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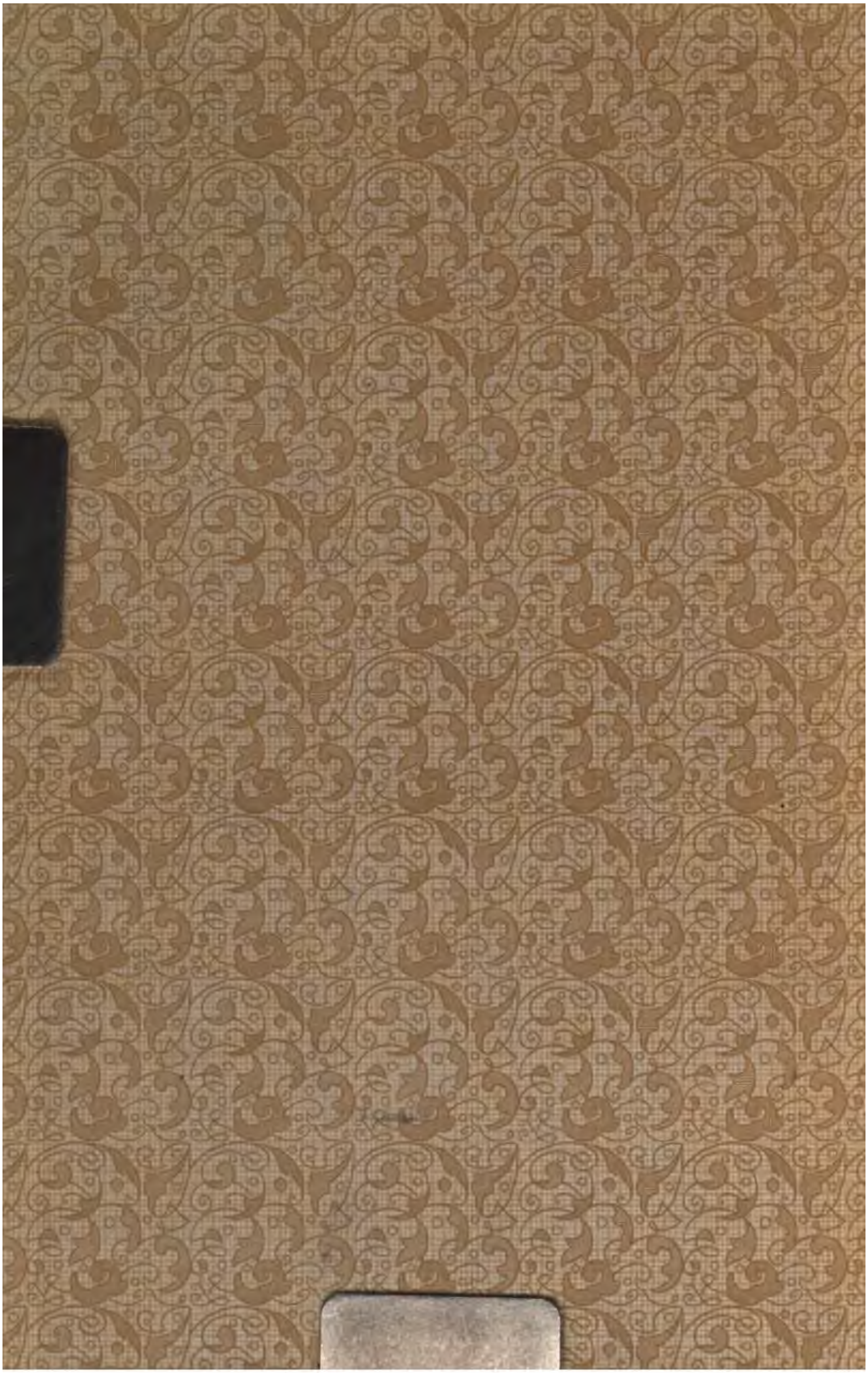

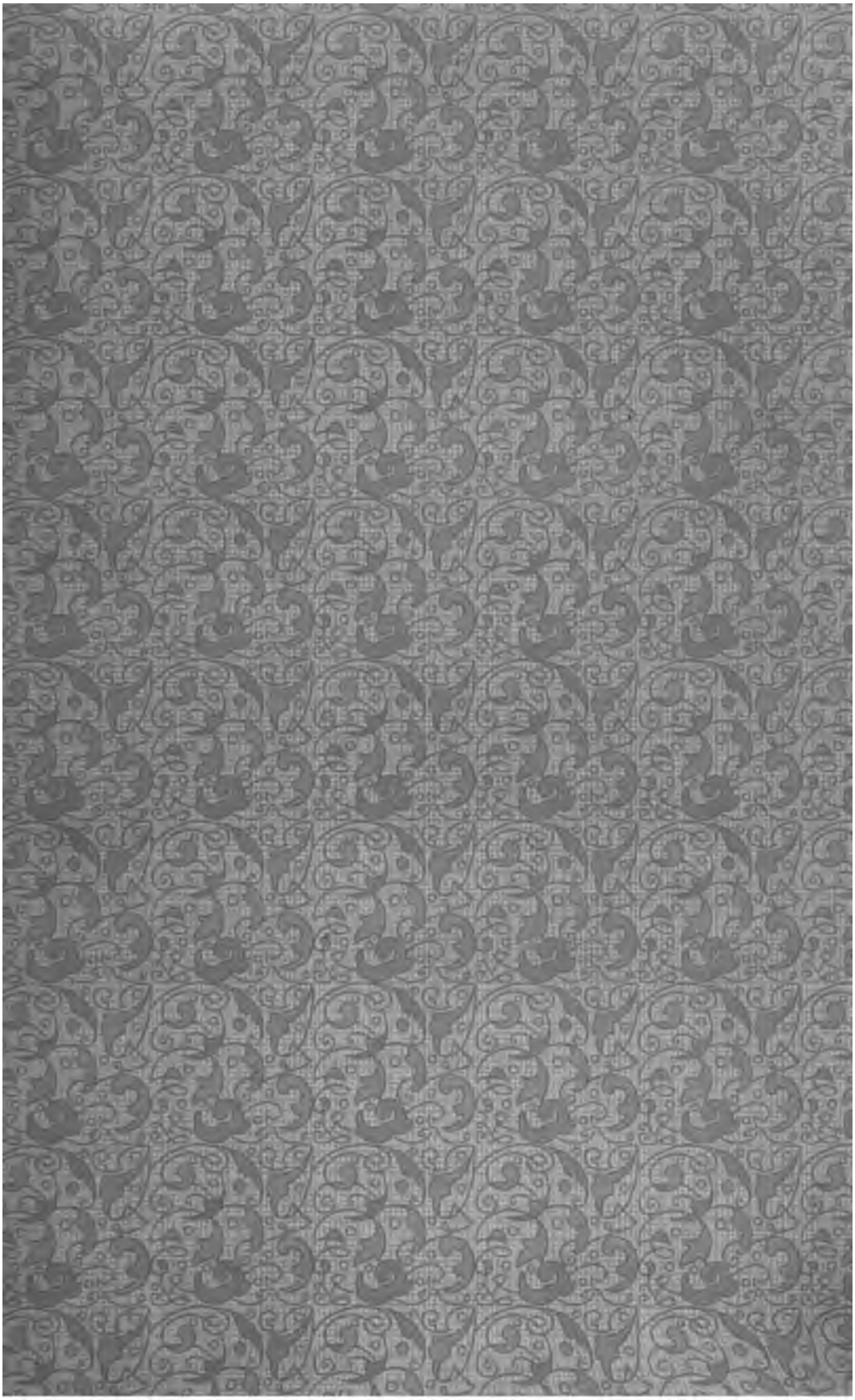

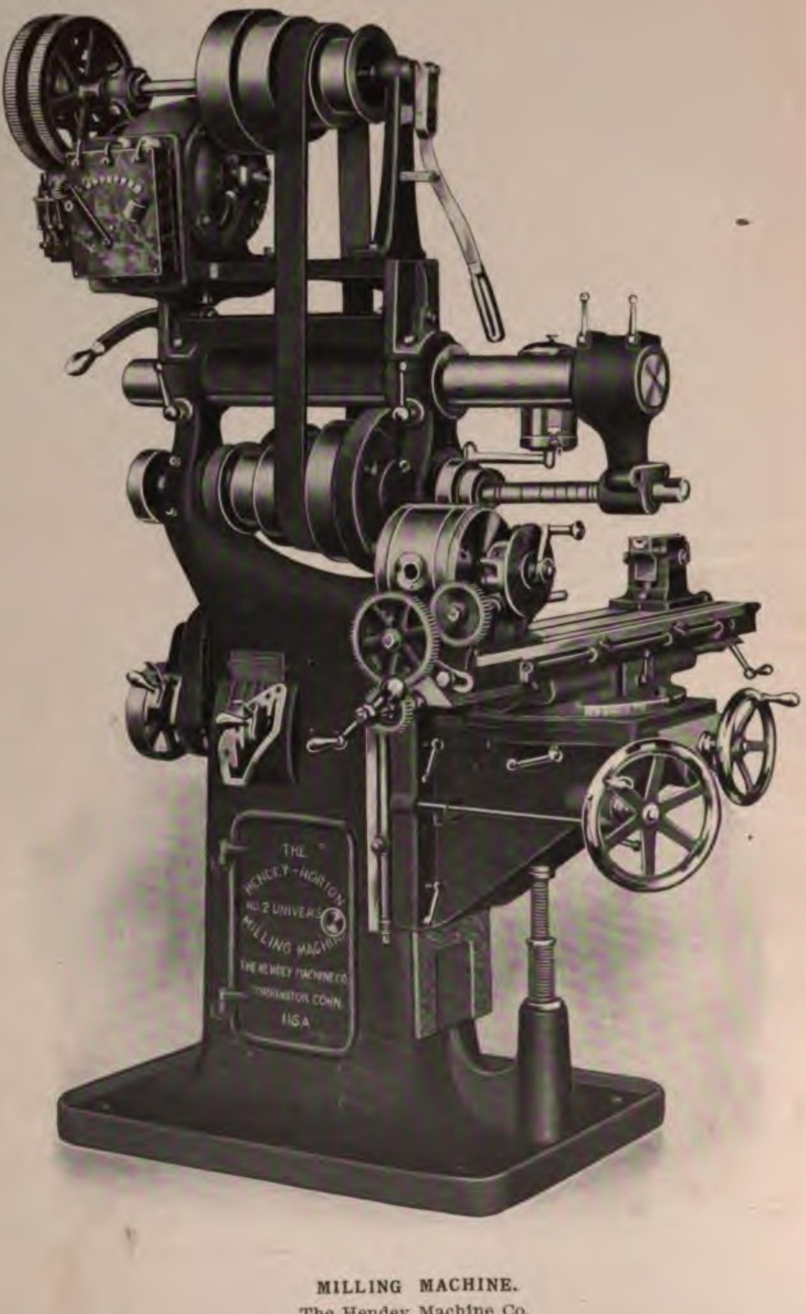

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OF

Modern Shop Practice

A Manual of

SHOP PRACTICE, PATTERN MAKING, MACHINE DESIGN,
FOUNDRY AND MACHINE SHOP WORK, FORGING,
TOOL MAKING, SHEET METAL WORK, STEAM,
REFRIGERATION, ELECTRICITY, ETC.

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SHOP EXPERTS, DESIGNERS AND ENGINEERS

Illustrated with over Two Thousand Engravings

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The standard technical literature of Europe and America has been freely consulted in the preparation of these volumes. The editors desire to express their indebtedness, particularly to the following eminent authorities, whose well-known treatises should be in the library of every Mechanic and Engineer.

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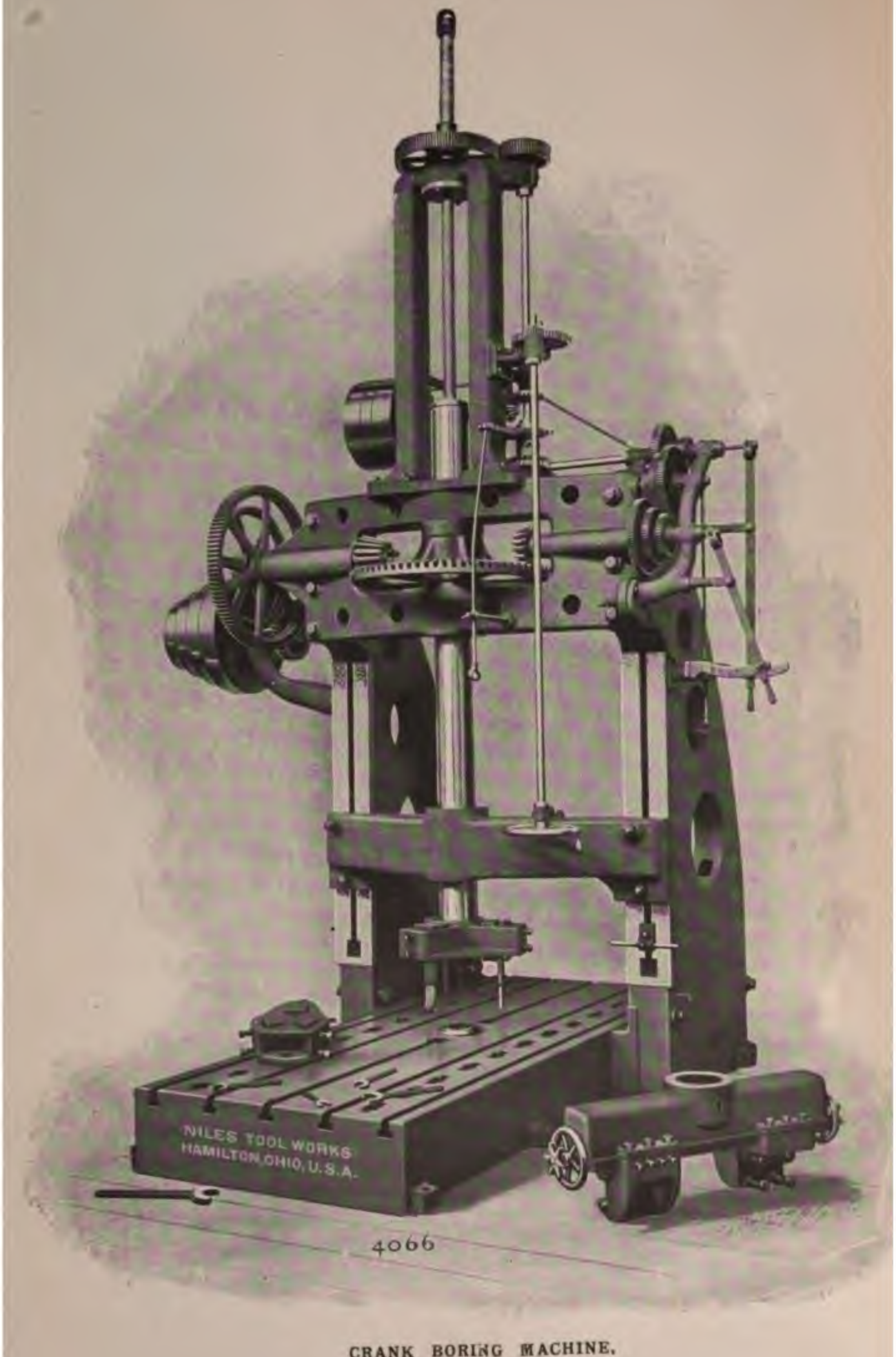
Introductory Note.

THE successful education of the man in the shop is a question of vital importance. The difficulties under which he toils in his struggle for advancement, and his daily labor, render impossible the usual means of education, and prevent the attending of a resident technical school. Probably the most successful substitute for such a school is the correspondence method of instruction. Thousands of mechanics are improving their conditions by devoting a half hour each day in systematic study under the direction of men who have had long experience in teaching, and in practical shop work. There are, however, many who cannot afford the time and expense necessary for even a correspondence school course. For such the Cyclopedia of Modern Shop Practice is prepared.

¶ This Cyclopedia is compiled from the most practical and most valuable Instruction Papers of the American School of Correspondence. These Instruction Papers have been prepared especially for home study and are intended primarily for such work. As their extended use in the American School of Correspondence has proved them to be of great practical value, and a successful means of instruction, they form a reliable treatise on the subject of shop practice.

¶ The correspondence student needs a thoroughly technical work free from superfluous theory; in like manner the reader of the Cyclopedia must have the necessary theories carefully explained, and the results of practical experience clearly pointed out. By giving the best material on shop practice to the busy man in the shop, the editors hope that he will achieve the success that results from a combined knowledge of theory and practice.



CRANK BORING MACHINE.
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TOOL MAKING.

PART I.

As generally understood, a tool maker is a machinist who has a greater knowledge of the trade than is simply sufficient to enable him to make such machines or parts of machines, as may be the regular product of the shop in which he may be employed.

The business of the tool maker is to make the tools for producing the different parts of the machine, implement or apparatus, and relates not only to cutting tools, but to jigs and fixtures for holding the work while the various operations are being done, and making the necessary gauges to determine when the different parts are of the correct size and shape. Also the making of the models for the different fixtures and gauges. In some shops where there is work enough of the two latter described classes, the tool makers regularly employed on this work are termed gauge makers and model makers respectively. Yet in the average shop the models and gauges and such special machinery as may be required are made by the tool maker.

In order to acquire any degree of success, the tool maker must not only be able to work accurately and within reasonable time, but he must have a knowledge of drafting to enable him to read quickly and accurately any ordinary drawings. Unless he can read decimal fractions readily and accurately, he will experience much difficulty when working to measurements that require accuracy within one ten thousandth part of an inch. As most of the measuring instruments used by the tool maker read to one thousandth part of an inch, and some of them to the ten thousandth part of an inch, or even closer, it will be readily seen that in laying off measurements for gauges, models, drill-jigs and similar work, a thorough knowledge of Arithmetic is essential.

A tool maker should be familiar with the accurate reading of the micrometer and of the vernier as applied to the vernier caliper, vernier depth gauge and vernier height guage. He must bear in mind when using the vernier caliper for inside measurements that it is necessary to add the amount of space occupied by the caliper points A A Fig. 1 to the apparent reading on the vernier side.

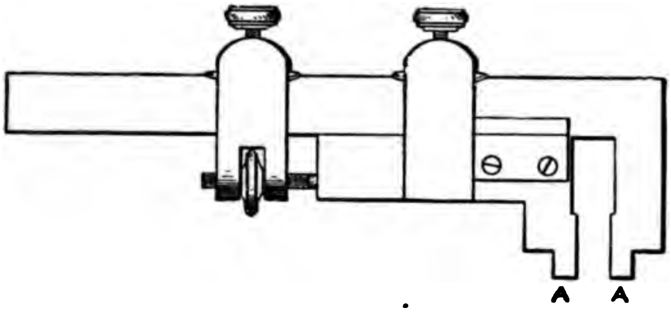


Fig. 1.

When measuring the distance between the centers of two holes as in Fig. 2, the vernier may be set so that the portions of the jaw marked A A Fig. 1 will exactly caliper the distance from B to B′ in Fig. 2. To the apparent reading of the vernier add the space occupied by the caliper points, and from this subtract one-half the diameter of each of the holes. It is necessary to

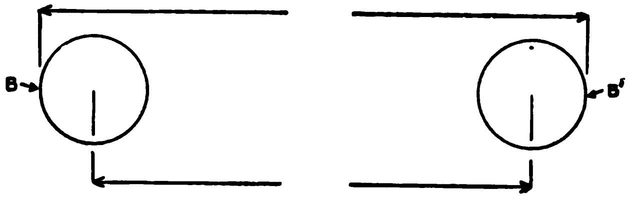


Fig. 2.

caliper the size of *each hole.* Do not take anything for granted when accurate measurements are necessary. A reamer *should always* cut an exact size, but experience proves that it does not always do so. If the size of the hole is taken for granted, a variation of .002 inch means an error of .001 inch in a measurement.

While extreme care should be exercised where accuracy is essential, there are parts of a tool where *approximate* measurements will do. If within $\frac{1}{16}$ inch is sufficiently accurate, it is folly to spend time to get a dimension within a limit of one ten thousandth part of an inch.

Approximate measurements are those made with the aid of calipers, dividers, surface guage, etc., set to an ordinary steel rule. Precise measurements are obtained by the aid of the various measuring instruments graduated to read to very small fractions of an inch. Also by the use of standard reference discs, and standard test bars, accurate within a limit of variation of $\frac{1}{50000}$ part of an inch. In using the micrometer, vernier or any of the measuring instruments supposed to give accurate readings, it is necessary to exercise great care in setting the tools. In setting the vernier it is well to use a powerful eye-glass in order that any error in setting may be so magnified as to be readily apparent.

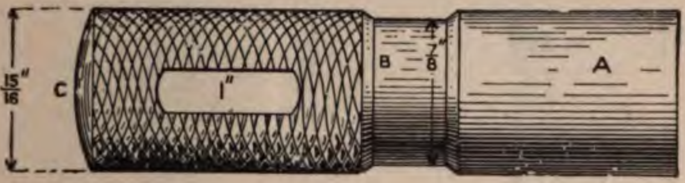


Fig. 3.

The difference between the two characters of measurements described — approximate and precise — may be readily seen in the plug gauge shown in Fig. 3. The gauge end A must be, when ground and lapped, *exactly* 1 inch in diameter, as shown by the stamped size on the handle C. The handle should be $\frac{15}{16}$ inch in diameter and knurled, and the neck $\frac{7}{8}$ inch. While the end marked A is necessarily a *precise* measurement, B and C are approximate, and an error of $\frac{1}{64}$ inch or more on either diameter would not interfere with the accuracy of the gauge. This does not mean that so great an amount of variation from given sizes should ever occur, but the illustration is given to show that the practical workman will never spend an unnecessary amount of time to produce accurate measurements when approximate measurements will do. On the other hand, all care possible should be taken when lapping the gauge end A to size.

Points to be Observed. Keep the working parts of any machine you may be running as clean as possible. Do not allow chips to collect on the shears (Vs) of your lathe. If these become roughed or worn, accurate turning cannot be done. Keep the machine thoroughly oiled, clean the oil holes out occasionally with a piece of wire, in order that the oil may get to the bearings.

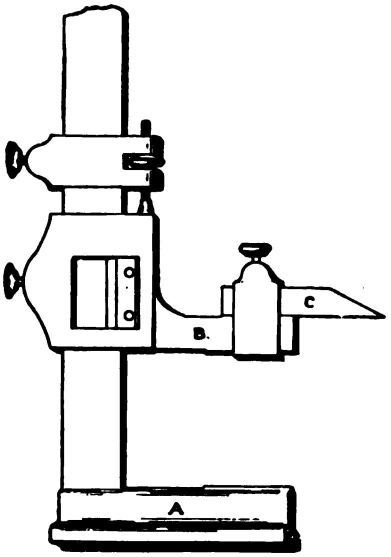


Fig. 4.

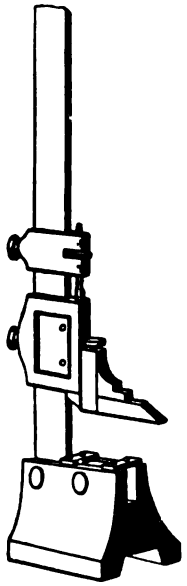


Fig. 5.

Keep the centers of your lathe in good condition, have them to gauge, and be sure the live center runs *true* before taking any finishing cuts. Try the center gauge on your countersink occasionally to see that it maintains its correct shape. Keep your center punch ground to a good point. It is advisable to grind the prick punch used in locating working points in some form of grinder having a chuck or collet to hold the punch while revolving it against the emery wheel; if the point is not perfectly round it will be impossible to indicate a piece of work perfectly on the faceplate of the lathe by means of the center indicator.

Special Tools. A vernier height gauge (Fig. 4) is a very handy tool for making drill jigs, templets and other tools requiring very accurate measurements, and for locating working points, holes or drill bushings. It is used for obtaining the height of projections from a plane surface, or the location of bushings in drill jigs, etc. The fixed jaw A is of sufficient thickness to allow the gauge to stand upright. An extension C attached to the movable jaw B can be used for scribing lines when laying off measurements. In the absence of a height gauge the regular vernier caliper may be made to answer the same purpose by making a base, which may be attached to the fixed jaw as shown in Fig. 5.

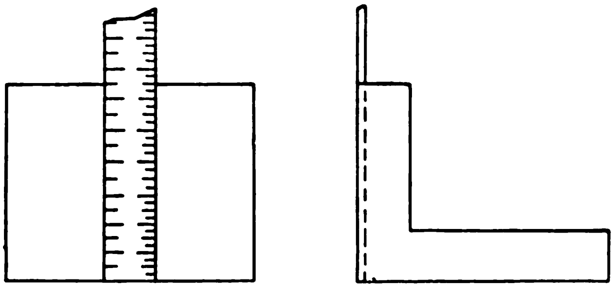


Fig. 6.

A small angle iron having a slot in the upright face to receive a scale for use in connection with a surface gauge when laying off measurements is shown in Fig. 6. The slot should be planed perfectly square with the base of the angle iron.

A pair of accurately machined V blocks is a necessary part of every tool maker's kit. If made of machinery or tool steel they will not need truing as often as if made of cast iron. After roughing out the V's, every surface should be planed square. They should be then clamped against the rail on the planer table by means of finger pieces, having previously trued the edge of the rail. The head of the planer should then be set to the proper angle, usually 45°, and one of the angles finished; the head may now be set over the opposite way and the other angle face planed. The tool used should be ground to give a smooth cut, as it is not advisable to do any finishing with a file or scraper.

A few small gauges of the most common angles will be found very convenient, as they can be used in places not accessible with the ordinary bevel protractor; the angles most commonly used are 60°, 65°, 70° and 80°. The form of gauge is shown in Fig. 7.

If the tool maker should be called on to make punch-press dies, one or more angle gauges, as shown in Fig. 8, will be found very useful. Many die makers use an adjustable square having a narrow blade which passes through the aperture in the die. The amount of clearance given is determined by the judgment of the workman; while this method does very well when practiced by an experienced man, it is rather uncertain when attempted by the novice. To get the proper clearance, the beginner should use the gauge shown in Fig. 8, called (improperly) a die maker's square.

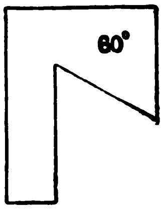


Fig. 7.

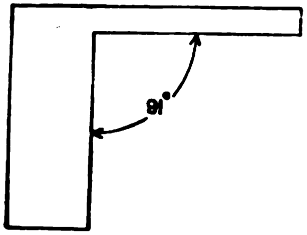


Fig. 8.

The angle depends on the nature of the stock, and the custom in the individual shop; but a set of three gauges, one 91°, one 91½°, and one 92° will meet the requirements, as the clearance is seldom less than 1° or more than 2°. The angle should be stamped on the wide part of the gauge, as shown in Fig. 7. To avoid springing out of shape the stamping should be done before the gauge is finish-filed at any point.

The tool maker should always have at hand a solution of blue vitriol for coloring the surface on which he is to draw lines. To make the solution, dissolve in a two-ounce bottle of water all the blue vitriol crystals the water will take up; to this add one-half teaspoonful of sulphuric acid. This produces a copper-colored surface when put on polished steel free from grease and dirt.

STEEL.

Tool steel is used for tools intended for cutting, pressing, or working metals or other hard materials to shape. In order to successfully work tool steel a knowledge of some of its peculiarities is necessary.

Carbon is the element in tool steel that makes it possible to harden it by heating to a red heat and plunging into a cooling bath. A bar of steel from the rolling mill or forge shop is decarbonized on its outer surface to a considerable depth; consequently this portion will not harden, or if it does the results will be far from satisfactory. For this reason if a tool is to be made having cutting teeth on its outer surface, it is necessary to select stock of somewhat greater diameter than the finish size, so that this decarbonized portion may be removed. About $\frac{1}{16}$ inch for sizes up to $\frac{1}{2}$ inch, $\frac{1}{8}$ inch for sizes up to $1\frac{1}{2}$ inches, $\frac{3}{16}$ inch for sizes up to 2 inches, and $\frac{1}{4}$ inch for sizes above 2 inches will usually be sufficient.

Tool steel may be procured in almost any form or quality. It is ordinarily furnished in round, octagonal, square or flat bars. Many tool makers prefer octagonal steel for tools which are to be circular in shape, but experience shows that steel of various shapes of the same make does not differ materially provided the quality and temper are the same.

Cutting tools should be made of high carbon steel if it is to be forged or hardened by skillful operators. If the steel is to be heated by an inexperienced man, it is not safe to select a steel having a high percentage of carbon.

For non-cutting tools, such as mandrels, it is well to select a low carbon steel (one per cent carbon or less), because with this steel there is not as great a tendency to spring when hardening.

Hammered steel is prized more highly than rolled steel by fine tool makers, but authorities do not agree on this point. It is generally conceded, however, that the best tools can be made from forgings if the heating and hammering have been correctly done. The steel should be heated uniformly throughout, and hammered carefully with heavy blows at first. Lighter blows should follow, and, when the piece passes from low red to black, great care is needed to prevent crushing the grain. Steel properly heated and hammered will have a close, fine grain.

Cutting from Bar. It is advisable when cutting a piece of stock from the bar to use a *cutting tool* of some description, such as a saw or cutting-off tool. It is decidedly poor practice to weaken the bar with a cold chisel and then break by a sudden blow or yank. This process so disarranges the particles of steel that they do not assume their proper relations with one another when hardened. If it is necessary to cut the steel with a chisel heat the bar to a *red heat*, as it may then be cut off without injury.

Centering. When centering, care should be taken that the center punch mark is exactly in the center of the piece on each end, so that an equal amount of the decarbonized material will be turned from all parts of the piece (see Fig. 9.) If centered as shown in Fig. 10 the decarbonized portion will be entirely removed at side marked B, and will not be on the side marked A, consequently when the piece is hardened the side marked B will be hard, while the opposite side A will be soft, or at least not as hard as B.

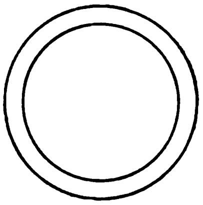


Fig. 9.

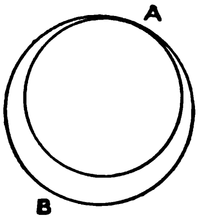


Fig. 10.

Straightening. A piece of tool steel that is to be hardened should *never* be straightened when cold. If it is bent too much to remove all the decarbonized steel when turning to size, it is best (generally speaking) to use a straighter piece of stock. But if the bent piece must be used, heat it to a red heat and straighten. A piece of steel straightened when cold is almost sure to spring when hardened.

ANNEALING.

In order that it may be soft enough to work easily, tool steel must be annealed. It can generally be bought in this condition cheaper than it can be annealed when needed in the factory. Annealing also removes the strains, or the tendency of the steel to crack and spring when hardened. Strains are caused by rolling and hammering in the steel mill or forge shop. In order to remove this tendency to spring, the piece of steel should be machined somewhere near to size, yet leaving sufficient stock to machine all over after the annealing. If it is a piece with a hole in it, such as a milling machine cutter blank, the hole should be drilled somewhat smaller than finish size ($\frac{1}{16}$ inch is the amount generally allowed) and the piece turned in a lathe to remove all the outer surface which contains the marks of the hammer or rolls. The piece is now ready for annealing. To anneal a piece of steel it should be heated to a uniform red heat and allowed to cool slowly. Steel may be annealed by any one of several methods.

Box Annealing. For this method it is necessary to have a furnace large enough to hold an iron box of sufficient size to take the piece to be annealed. To do this work cheaply, enough pieces should be annealed at a time to fill one or more boxes, according to the capacity of the furnace.

The material used in packing the box is wood charcoal, which should be ground or pounded until the particles are about the size of a pea. A layer of charcoal covering the bottom to a depth of one inch is first placed in the box, then a layer of steel. The different pieces should not come within $\frac{1}{2}$ inch of each other nor within 1 inch of the box at any point. The spaces between the pieces are filled with the charcoal, and they are covered to a depth of 1 inch. Another layer of steel may be put in if the box is of sufficient size. When within $1\frac{1}{2}$ inches of the top fill with charcoal, tamp down, put on the cover, and lute around the edges with fireclay, to prevent the direct heat of the fire entering the box.

Test Wires. There should be several $\frac{1}{4}$-inch holes drilled through the cover near the center, and through each of these a piece of $\frac{3}{16}$ inch wire should be placed. The wires should extend to the bottom of the box and project about 1 inch above the top of the cover in order to be readily grasped by the tongs. These wires are intended to be drawn from the box in order to determine when the contents are red hot. The box should be placed in the furnace. After the box has become thoroughly heated, one of the wires may be drawn out by means of a pair of long tongs. If no such tongs are available the legs of ordinary tongs may be lengthened by pieces of gas pipe. Note the time when the wire is red hot the entire length. If not red hot draw another in ten or fifteen minutes, and continue doing so until a wire is drawn that is red the entire length. The work should be timed from the time the box is heated through; this is shown by the wire.

The heat should be maintained a sufficient length of time to insure a uniform heat, which should not be allowed to go above a full red. The length of time the pieces remain in the fire depends somewhat on the size; for steel 2 inches and under, one hour after the box is heated through will do; larger pieces require a longer time. After running for the necessary length of time the heat should be shut off and the boxes allowed to cool slowly; the pieces should be left in the box until cold.

When there are no facilities for annealing by the method described, the piece may be heated to a uniform red and placed on a piece of board in an iron box, having one or two inches of ashes under the board. A second piece of board should be placed on the steel and the box filled with ashes. The pieces of wood will smoulder and keep the steel hot for a long time.

Another common method of annealing tool steel is to heat the piece to a red heat and bury it in ashes or lime. This is likely to give unsatisfactory results unless the ashes or lime are also heated. This can be accomplished by first heating a large piece of iron and burying in the contents of the annealing box. When the steel to be annealed is sufficiently heated the piece of iron may be removed and the piece to be annealed put in its place and thoroughly buried in order that it may take a long time in cooling; it should be allowed to remain in the ashes or lime until cold.

There is another method of annealing practiced in some shops, which answers in an emergency, but it is not to be recommended for general use. This is known as the *water anneal.* The piece of steel should be heated to a *low red*, making sure that the heat is uniform throughout. It should be removed from the fire and held in the air where no draft can strike it until no trace of red can be seen, even if the piece is held in a dark place; it should then be plunged in water, and allowed to remain until cold. Better results may be obtained if plunged in soapy water or oil.

Long pieces which spring when annealed should not be straightened when cold, if they are to be hardened.

HARDENING.

Tool steel may be hardened by heating to a low red heat and plunging in some cooling medium, as water, brine or oil.

Heating. A piece of steel should never be heated any hotter than is necessary to give the desired result. The heat necessary varies with the make of the steel, the amount of carbon it contains, the size and shape of the piece, and the purpose for which it is to be used. Much depends on heating uniformly; a piece of steel should be given a *uniform heat throughout*, the edges and corners should be no hotter than the center, and the interior should be of the same temperature as the surface. If not, the piece is likely to crack in the cooling bath, on account of the uneven changes which take place in the molecular structure. While it is highly important that the steel is heated no hotter than is necessary, yet it is of *much more* importance that it be heated uniformly.

If the piece is heated in an ordinary forge, be sure that the air from the blast does not strike it. For a large piece build a large high fire; have it well heated through before putting in the steel. Use the blast only enough to keep a lively fire; have the steel well buried in the fire in order that the air may not strike it.

Cooling. When the piece is uniformly heated it should be plunged into a suitable bath to give it the proper hardness. It must be worked rapidly up and down, or around in the bath in order to get it away from the steam generated by the red hot steel coming in contact with the liquid, and also that it may constantly come in contact with the cooler parts of the bath. If the piece is long and slender it must be worked up and down; if it is short with teeth on the outer edge, as a milling machine cutter, it should be worked around rapidly in order that all the teeth may be cooled uniformly. If it is flat and has a hole through it whose inner walls must be hard, it should be swung back and forth in order that the bath may pass through the aperture and at the same time strike both faces.

If the tool is not to be hardened all over, and it is necessary to heat it higher than the point where the hardening is to stop, it may be dipped in the bath to a point a trifle higher than we wish it to harden, and then worked up and down a little. If this is not done there will be a line where the piece is expanded at one side and contracted on the other; it is likely to crack at this line, which is called a "water line."

Delicate articles, or those tools having long projections or teeth, should not be dipped in a bath of very cold water or brine; for such work a tepid bath gives better results.

Steel should always be hardened at a heat that leaves the grain *fine* when the piece is broken. This can be determined by hardening and breaking a small piece from the same bar from which the tool to be is made. A *coarse grain* denotes a heat higher than the steel should receive.

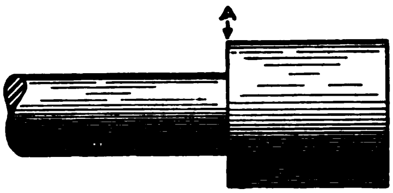


Fig. 11.

It will be found necessary when heating some kinds of steel to put the articles in an iron tube so that air cannot come in contact with them; this is especially true when hardening such tools as taps or formed mills whose outer surfaces cannot be ground, because the oxygen in the air acting on the carbon at the surface of the piece of steel *burns* it, leaving the surface decarbonized. Better results can be obtained with any tool if it is kept from the action of the fire when heating for hardening.

When hardening a piece having a shoulder A, on the outside, as shown in Fig. 11, or inside, as shown in Fig. 12, hardening should not stop at the shoulder, as the unequal strains occasioned by the contraction of the hardened part at the shoulder are likely to cause it to crack at that point. The piece should not be hardened as high as the shoulder, but should it be necessary to do so, it is well to harden a little beyond.

Citric Acid Bath. An excellent bath for hardening small pieces may be made by dissolving one pound of citric acid crystals in one gallon of water. It should be kept tightly closed when not in use or it will evaporate. Small tools heated to a low red heat and dipped in this solution harden more uniformly than when immersed in clear water.

Pack Hardening gives excellent results with pieces that cannot be hardened by the methods ordinarily employed without risk of springing or cracking. The article is packed in an iron box with some carbonaceous material, and subjected to the action of heat to allow it to absorb enough carbon to harden in oil. While this method is not generally used, it is very valuable when hardening such pieces as milling machine cutters, blanking dies for punching presses, gauges, and taps where it is necessary that the diameter and pitch are not altered. The carbonaceous material is charred leather, which should be ground or pounded very fine (usually about one-half the size of a pea), and mixed with an equal quantity (volume) of wood charcoal whose granules are of about the same size. These should be thoroughly mixed. An iron box somewhat larger each way than the piece to be hardened should be selected. A layer of the packing material one inch deep should be placed in the bottom of the box and the piece laid on this; the box should then be filled with the packing material and tamped down. Fill the space between the cover and the box with fire clay, thus sealing it so that the gases in the box cannot escape and the direct heat of the fire cannot get into the box.

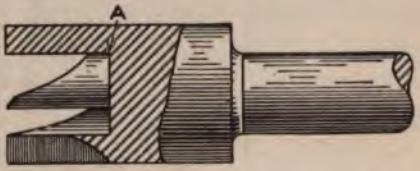


Fig. 12.

It is much more economical to pack a number of pieces at a time, as several may be hardened at the cost of one, and at a saving in packing material. The pieces should be wired with ordinary iron binding wire of a sufficient size to sustain the weight when the wire is red hot. One end of the wire should project over the outside edge of the box, and should be covered with the luting of fire clay. Several holes should be drilled near the center of the cover for test wires, as when annealing. The wires should extend to the bottom of the box. The box may now be heated sufficiently to charge the pieces with carbon. As steel does not commence to absorb carbon until it is red hot, the time is determined by means of the test wires as described under "Annealing." For ordinary tools ½ inch diameter and under, run 1 hour to 1½ hours after it is red hot; pieces from ½ inch to 1 inch diameter, 2 to 2½ hours; pieces from 2 to 3 inches diameter, 2½ to 4 hours. The above must be varied according to the nature of the work.

After remaining in the furnace, the box should be taken out, the cover removed, and the piece taken out by means of the wire attached to it. It should then be immersed in a bath of *raw linseed oil.* The piece should be worked around in the bath until the red has disappeared; it may be then lowered to the bottom of the bath and allowed to remain until cold.

When a piece of steel one inch in diameter or larger is hardened, it should be reheated over the fire immediately on taking out of the bath, in order to avoid cracking, from the strains caused by molecular changes which take place after the outside surface is hardened and unable to yield to the internal strains. Reheating the surface to a temperature of about 212° will accomplish the desired result without materially softening the steel.

TEMPERING.

The hardening of a cutting tool makes it too brittle to stand up well when in use, and consequently it is necessary to soften it somewhat. This is known as "drawing the temper," and is accomplished by reheating to the proper temperature, which is ordinarily determined by the color of the surface of the tool, which must be brightened previous to this operation. As the piece of steel is heated, a light, delicate straw color will appear; then, in order, a deep straw, light brown, darker brown, light purple, dark purple, dark blue, pale blue, blue tinged with green, black. When black, the temper is gone. These colors furnish a guide to the condition of hardened steel.

The following list gives the color denoting the tempers generally used for tools:

Light straw	For lathe and planer tools, scrapers for brass, etc.
Deep straw	For milling cutters, reamers, large taps, etc.
Brown	For twist drills, drifts, flat drills for brass, etc.
Light purple	For augurs, screw slotting saws, etc.
Dark purple	For saws for wood, cold chisels, screwdrivers, etc.

The following table gives the degree of heat corresponding to the different colors mentioned in the previous table.

Light straw	**430 degrees F.**
Deep straw	**460 degrees F.**
Brown	**500 degrees F.**
Light purple	**530 degrees F.**
Dark purple	**550 degrees F.**
Dark blue	**570 degrees F.**
Pale blue	**610 degrees F.**
Blue tinged with green	**630 degrees F.**

When work is tempered in large quantities the above method is expensive. Also it is not as reliable as when the articles are heated in a kettle of oil, using a thermometer for indicating the temperature. A piece of perforated sheet metal or wire cloth should be used to keep the articles two or three inches from the bottom of the kettle. A perforated sheet iron pail two inches smaller in diameter than the kettle, resting on a piece of iron, or a frame placed in the bottom will keep the pieces from the sides and bottom of the kettle.

The thermometer should be placed in the kettle outside the pail in order that the bulb may be at the same depth as the lower pieces.

Case Hardening. When an article of wrought iron or machinery steel is to have a hard surface it is treated while red hot with some material which forms a coating or case of steel, which hardens if dipped in water while red hot. Small articles such as nuts, screws, etc., may be case hardened by heating red hot and covering with a thin layer of powdered cyanide of potassium; when the cyanide of potassium melts, the article may be heated red hot again; it is then plunged into water. Care should be exercised when using this substance, as it is *extremely poisonous.*

The above method may be used for hardening a few pieces quickly, but it is not recommended for large quantities of work. When many pieces are to be case hardened at a time, the following method will be found less expensive and much more satisfactory:

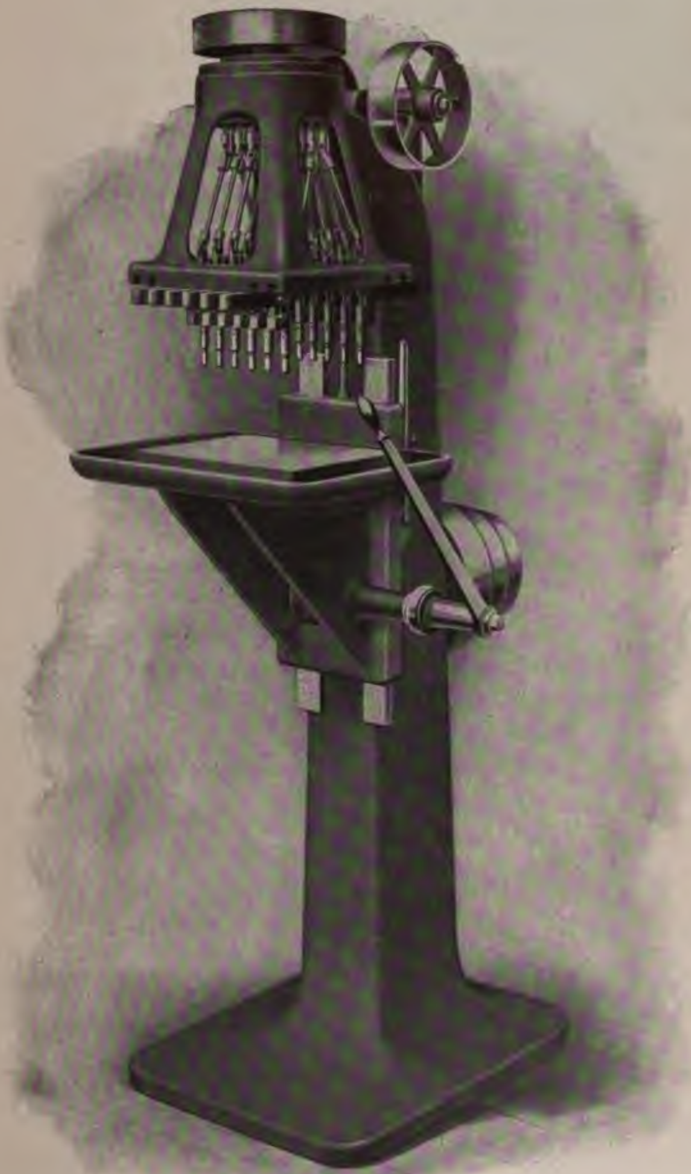
Granulated raw bone and granulated charcoal should be mixed in equal quantities, and a layer of this mixture placed in an iron hardening-box to the depth of 1 or 1½ inches. A layer of articles is then placed on this; the pieces should not come within ½ inch of each other, nor within 1 inch of the walls of the box at any point; they should be covered with a layer of the mixture of bone and charcoal to the depth of ½ inch. Successive layers may be placed in the box until it is filled to within 1 inch of the top, when the cover may be put in place and the edges luted with fire clay. The test wires should be used as described for annealing. The heating should be timed from the time the contents of the box are red hot, which can be determined by the test wires. The length of time the work is allowed to run while red hot depends upon the desired depth of the hardened surface; generally carbon will penetrate wrought iron ⅛ inch in twenty-four hours, but as it is rarely necessary to harden deeper than $\frac{1}{32}$ inch, the work may be kept red hot three to four hours. With small pieces, the contents of the hardening-box may be dumped into a tank of running water; if the pieces are large, it is necessary to dip them one at a time in a bath, the same as for tool steel. For extreme toughness, the pieces, if small, may be dumped into a perforated sheet-metal pan and the *packing material sifted out*, after which they may be placed in a bath of oil; if not sifted out, the packing material will stay at the top of the oil and set fire to it. If the pieces are large, they may be dipped one at a time.

Spring Tempering. A piece of steel may be spring tempered by first hardening and then drawing the temper to a degree to which the piece, when bent, will return to its normal shape, when the pressure is removed. This may be accomplished by covering the surface with tallow or some animal oil, and then heating until the oil catches fire from the heat in the piece.

DRILLS.

The forms of drills commonly used in the machine shop are the flat drill, single-lip drill and twist drill.

Flat Drills, intended for use in the engine lathe for chucking, are usually forged to shape in the forge shop. After centering the end, which rests on the tail center of the lathe, the lips are ground to shape and the drill is ready for use. A drill of this description is shown in Fig. 13.



MULTIPLE SPINDLE DRILL.
Pratt and Whitney Co.

If it is necessary to have the drill cut nearly exact to size, it should be forged somewhat wider than finish size, and the edges turned in the lathe as in Fig. 14. The projection A must be left on the cutting end to provide a center for turning. If the drill is to be ground to size after hardening, the projection must be left on until the grinding has been done, but, ordinarily, this class of drill is not intended to cut exact enough to require grinding.

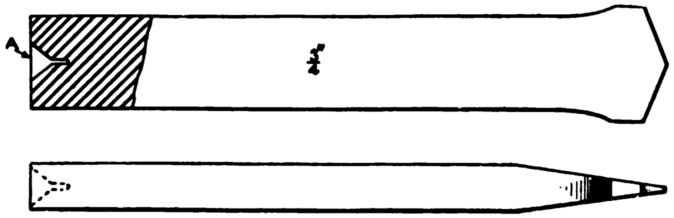


Fig. 13.

If the edges of the drill are not to be ground to size, they should be draw-filed a small amount to avoid binding. The filing should not come within $\frac{1}{64}$ inch of the edge, and should be only a small amount (.003 or .004 inch will be found sufficient); if given too much relief the drill will jump and chatter. The shank should be somewhat smaller ($\frac{1}{32}$ to $\frac{1}{16}$ inch) than the cutting end

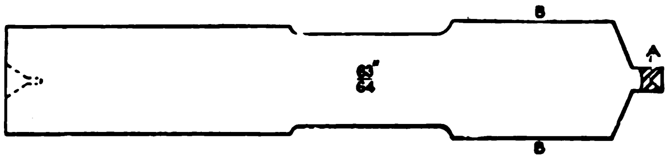


Fig. 14.

in order not to touch the sides of a hole drilled deep enough for the shank to enter. The center in the shank end should be large, to insure a good bearing on the tail center of the lathe, as shown at A, Fig. 13.

When hardening, the drill should be heated a *low red* to a point above the cutting end, preferably about one-half the length of the portion turned smaller than the ends. When dipped in the bath it should be plunged about one inch above the cutting end. To insure good results it should be worked up and down and around in the bath, which may be either water or brine. The temper should be drawn to a brown color.

When a flat drill is intended for use in a drill press, the shank is left round, in order that it may be held in a chuck or collet.

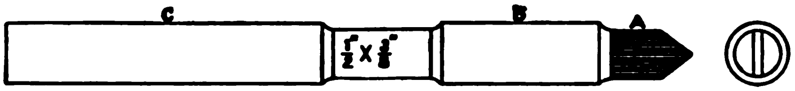


Fig. 15.

Transfer Drill. Another form of flat drill termed a transfer drill, is very useful when a small hole is to be transferred from a larger. The shank C, Fig. 15, may be made of any convenient size; the portion B is of the size of the larger hole, while A is of the size of the hole to be transferred, and is a short *flat* drill.

When making this drill, if a lathe is used having draw-in split chucks, the drill may be made from drill rod, which should be enough larger than finish size to allow B to be turned, to insure its running true with A; the cutting part A may be milled or filed to thickness. The cutting lips are then backed off, and the drill hardened. It should be hardened high enough so that A and B are hard, as the portion A does the cutting, while B, being a running fit in a hole, is likely to rough if it is soft.

Fig. 16.

To harden it should be heated in a tube and dipped in water or brine, and worked up and down, to avoid soft spots caused by steam keeping the water from the metal, as sometimes happens when a piece has different sizes close together. The cutting portion A should be drawn to a deep straw color; B should be left as hard as possible, to resist wear.

Straightway, or straight fluted drills, have the flutes cut parallel to a plane passing through the axis of the drill, as shown in Fig. 16. They are used in drilling brass, and in drilling iron and steel when the holes break into one another, as shown in Fig. 17.

The smaller sizes may be made of drill rod. After cutting to length, the blank may be put in a chuck in the lathe and the end pointed to the proper cutting angle. When milling the flute, the shank may be held in the chuck on the end of the spiral head spindle. The head should be set at an angle that makes the flute deeper at the cutting end of the drill than at the shank end; this causes an increase of thickness at the shank, thus making the drill stronger than if the flute were of uniform depth throughout. The milling cutter should be of a shape that will make the cutting face of the drill a straight line when the drill is ground to the proper cutting angle. The corner should be somewhat rounded. The general shape of the cutter is shown in Fig. 18.

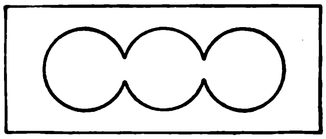


Fig. 17.

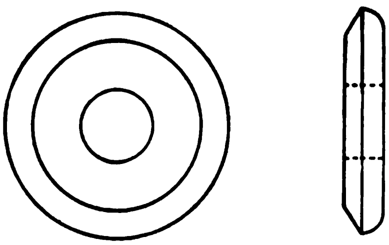


Fig. 18.

Single Lip Drill. For certain classes of work the single lip drill is very useful. Having but one cutting edge its action is similar to that of a boring tool used for inside turning in the engine lathe. The body of the drill being the size of the hole drilled insures its cutting a straight hole, even when used in drilling work partly cut away, or castings having blow-holes or similar imperfections. It does not cut as rapidly as the other forms, consequently is not used where a twist drill would do satisfactory work. Fig. 19 shows a form of single lip drill to be used with a bushing. The steel for this drill should be somewhat larger than finish size, in order that the decarbonized surface may be removed;

the cutting end A and the shank B should be turned .014 to .020 inch larger than finish diameter to allow for grinding after the drill is hardened. The portion C should be turned to finish size and stamped. In order that the drill may be ground to size after it is hardened it will be found necessary to face the end back, leaving the projection containing the center as shown at A in Fig. 20. The cutting end should be milled to exactly one-half the diameter of B. After milling, the face C should be draw-filed until it is flat and smooth. When hardening, the drill should be slowly heated to a low red, a trifle higher than the portion that is to be cutting size; it should be plunged in a bath of warm water or warm brine in order to avoid as far as possible any tendency to springing or cracking in the projection A. The tendency to crack is due to its peculiar shape and the difference in its size and that of the drill. After hardening it may be drawn to a straw color.

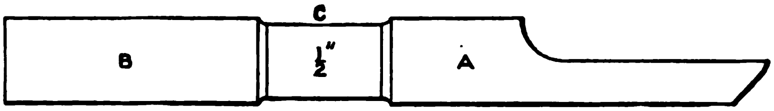


Fig. 19.

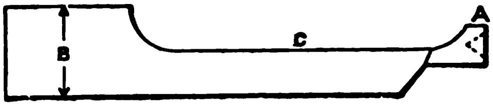


Fig. 20.

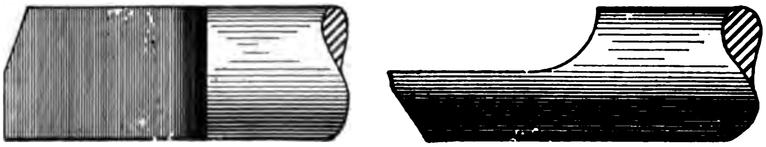


Fig. 21.

When grinding it is advisable to grind the shank first, in order that the grinding machine may be adjusted to grind straight;

after grinding the shank and cutting end to size, the projection A may be ground off, and the cutting end given the required shape, as shown in Fig. 21.

When a single-lip drill is to be used on iron and steel and not upon brass, it may be made to cut more freely by giving the cutting-face rake, as shown in Fig. 22. This may be done by milling the portion A to the proper dimensions, which should be one-half the diameter of the blank. The end and sides of the drill may now be coated with the blue vitriol solution and the desired shape marked out, after which it may be placed in the milling machine vise at the proper angle, and the required amount of rake given by means of small end cutters. After giving the necessary end clearance as shown in the two views of Fig. 22, the drill is ready for hardening.

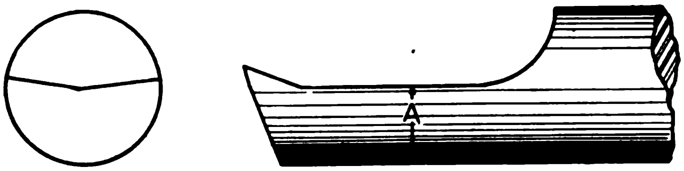


Fig. 22.

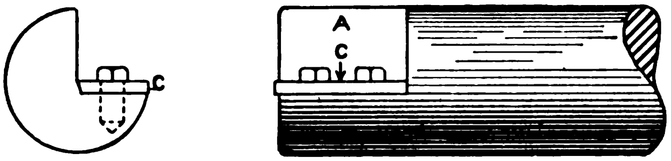


Fig. 23.

In order to adjust a drill of this kind to compensate for wear, it may be made as shown in Fig. 23, in which one-quarter of the circumference is cut away at A and a blade or cutter fastened in position; the top face of the cutter should be radial. To compensate for wear, pieces of paper or thin sheet metal may be inserted under the blade.

When cutting away the portion A, three holes may be drilled, as shown in Fig. 24. If square corners are desired, care should be taken that the holes are located so that they will machine out when milling to the proper dimensions. After drilling, the body of the drill may be placed in a vise in the shaper, and by the use of a cutting-off tool (parting tool) the portion may be removed, but as it would be impossible to cut to finish dimensions it will be necessary to finish with small end milling cutters, holding the tool in the chuck on the spindle of the spiral head. After machining one surface, the spindle may be revolved one quarter turn and the other surface machined; this insures square corners, and two surfaces at right angles to each other. The surface on which the cutter is to rest should be cut below the line of center, so that the top edge of cutter may be radial; that is, it should be cut the thickness of the cutter below a line passing through the center. See Fig. 23.

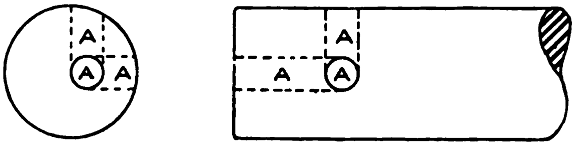


FIG. 24.

The cutter should be made of tool steel; two holes should be drilled for the fastening screws. After fastening the cutter in position it may be turned to the proper diameter by running the body of the tool in the steady rest of the lathe. Care should be used not to cut into the body or holder. After turning to size and facing the end square, the cutter may be removed from the holder, and necessary clearance given the end by filing; the outer edge may be draw-filed in order to smooth it, and a slight clearance given to prevent binding; this may be done by removing a trifle more stock at the bottom than at the top edge. To harden it should be heated to a low red heat and dipped in luke-warm water; the temper may be drawn to a straw color.

Twist Drills. In general it is cheaper and more satisfactory to buy twist drills than to attempt their manufacture in the ordinary machine shop; but at times a *special* size or length of drill is needed, or, for some cause, it is necessary to make them.

For the smaller sizes it is best to use commercial drill rod. For drills larger than ½ inch diameter select larger stock and turn it to the desired size. If true holes of the size of the drill are required, it is advisable in the case of drills larger than ½ inch diameter, to turn them .010 to .015 inch larger than finish size, and grind to the required size after hardening. A projection (Fig. 25) containing the center should be left on the cutting end of the drill until after the grinding has been accomplished. After cutting the flutes and grinding the drill, the projection may be ground off and the cutting lips ground to the proper shape, as shown in Fig. 26.

Fig. 25.

When making drills of the smaller sizes from drill rod, the blanks may be cut and pointed to the proper angle on the cutting end; this may be done in the lathe holding the blank in a chuck.

Fig. 26.

The proper angle is 59° from one side of the blank. When milling the flutes of a twist drill on a universal milling machine, the shank of the drill, if straight, may be held in a chuck or collet of the right size, and if very long may be allowed to pass through the spiral head.

The following explanation and table are taken from Brown & Sharpe Co.'s book, entitled "Construction and Use of Milling Machines," and are intended for use with the cutters manufactured by them when cutting the flutes in twist drills.

The cutter is placed on the arbor directly over the center of the drill, and the bed is set at the angle of spiral, as given in the following table:

Diameter of Drill.	Thickness of Cutter.	Pitch in Inches.	Gear on Worm.	First Gear on Stud.	Second Gear on Stud.	Gear on Screw.	Angle of Spiral.
$\frac{1}{16}$	.06	.67	24	86	24	100	16° 20′
$\frac{1}{8}$	.08	1.12	24	86	40	100	19° 20′
$\frac{3}{16}$	.11	1.67	24	64	32	72	19° 25′
$\frac{1}{4}$	.15	1.94	32	64	28	72	21°
$\frac{5}{16}$	.19	2.92	24	64	56	72	20°
$\frac{3}{8}$	.23	3.24	40	48	28	72	21°
$\frac{7}{16}$	.27	3.89	56	48	24	72	20° 10′
$\frac{1}{2}$	.31	4.17	40	72	48	64	20° 30′
$\frac{9}{16}$	.35	4.86	40	64	56	72	20°
$\frac{5}{8}$	.39	5.33	48	40	32	72	20° 12′
$\frac{11}{16}$	.44	6.12	56	40	28	64	19° 30′
$\frac{3}{4}$	.50	6.48	56	48	40	72	20°
$\frac{13}{16}$	.56	7.29	56	48	40	64	19° 20′
$\frac{7}{8}$	.62	7.62	64	48	32	56	19° 50′
$\frac{15}{16}$	.70	8.33	48	32	40	72	19° 30′
1	.77	8.95	86	48	28	56	19° 20′

The depth of groove in a twist drill diminishes as it approaches the shank, in order to obtain increased strength at the place where the drill is otherwise generally broken. The variation in depth depends on the desired strength or the use of the drill. To obtain the necessary variation of depth, the spindle of the spiral head is elevated somewhat, depending on the length of the flute to be cut; when less than 2 inches in length the angle should be $\frac{1}{2}$ degree: 5 inches and over in length, 1 degree. Usually this will be found satisfactory, but for extremely long drills the elevation must exceed these amounts. The outer end of the drill must be supported, as shown in Fig. 27, and when small should be pressed down firmly until the cutter has passed over the end.

It is somewhat better to use left-handed cutters, so that the cut may begin at the shank end, in order to lessen the tendency of lifting the drill blank from the rest. When large drills are held by the centers the head should be depressed in order to decrease the depth of the groove as it approaches the shank.

Another very important operation on the twist drill is that of "backing off" the rear of the lip, to give it the necessary clearance. In Fig. 28 the bed is turned to about $\frac{1}{2}$ degree, as for cutting a right-hand spiral, but as the angle depends on several conditions it will be necessary to determine what the effect will be under different circumstances. A study of Fig. 28 will be sufficient for this by assuming the effect of different angles, mills, and the pitches of spirals. The object of placing the bed at an angle is to cause the mill E to cut into the lip at C and have it just touch the surface at C. The line R being parallel with the face of the mill, the angular deviation of the bed is clearly shown at A in comparison with the side of the drill.

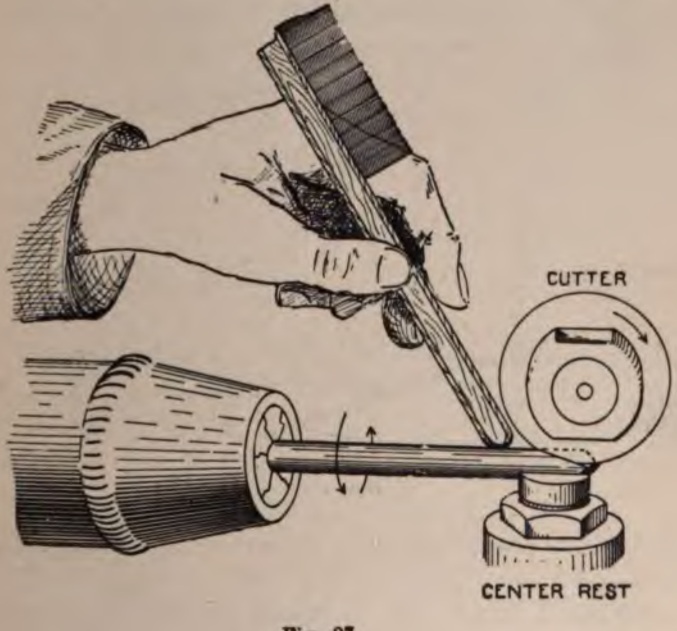


Fig. 27.

While the drill has a positive traversing and relative movement, the edge of the mill at C must always touch the lip a given distance from the front edge, this being the vanishing point; the other surface forming the real diameter of the drill is beyond the reach of the cutter, and is left to guide and steady it while in use.

The point C as shown in the enlarged view, Fig. 28, shows where the cutting commences and its increase until it reached a maximum depth at C, where it may be increased or diminished according to the angle employed in the operation; the line of cutter action being represented by I I.

Before backing off, the surface of the smaller drills in particular should be oxidized by heating until it assumes some distinct color to clearly show the action of the mill on the lip of the drill, for, when satisfactory, a uniform streak of oxidized surface, from the front edge of the lip back, is left untouched by the mill, as represented in the cut at E.

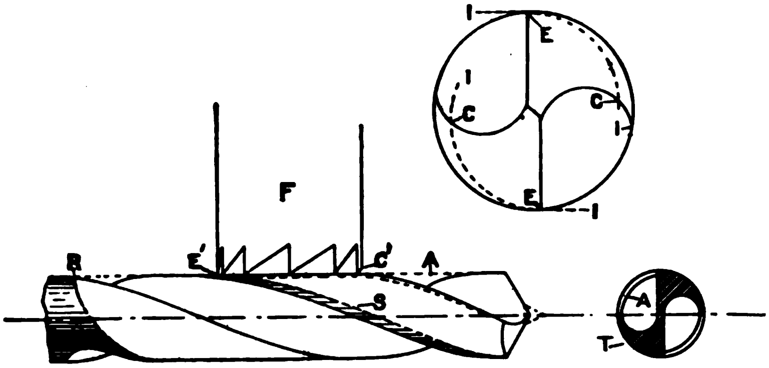


Fig. 23.

If the drills are to be ground without being centered, pointed projections (60°) may be made on the ends as shown in Fig. 28; these projections may be run in female centers in the grinding machine. If tapered back about .003 inch in 6 inches it will be found that the clearance thus obtained will cause them to run much better.

Hardening Twist Drills. Twist drills are hardened by special processes which, generally speaking, are not understood outside the shop where the drills are made. Very good results, however, may be obtained if the drills are heated somewhat and dipped into a solution of the following:

Pulverized charred leather	1 pound
Fine Family Flour	1½ pounds
Fine Table Salt	2 pounds

The charred leather should be ground or pounded until fine enough to pass through a number 45 sieve. The three ingredients are thoroughly mixed while in the dry state, and water is then added *slowly*, to prevent lumps, until the mixture formed has the consistency of ordinary varnish.

After the drill has been dipped in the mixture it should be laid in a warm place to dry; when thoroughly dried the drill may be heated in a tube, or preferably in a crucible of red-hot lead until it is a low red, when it may be plunged in a bath of lukewarm water, or brine; small drills may be dipped in a bath of oil. The drill must not be put in red-hot lead until the coating is thoroughly dried, as the moisture may cause minute particles of lead to fly in all directions, endangering the eyes of the operator. After hardening, the temper may be drawn to a full straw color. If several drills are hardened at a time the temper may be drawn by placing them in a kettle of oil over a fire gauging the amount of heat by a thermometer, as explained under heading of "Drawing Temper."

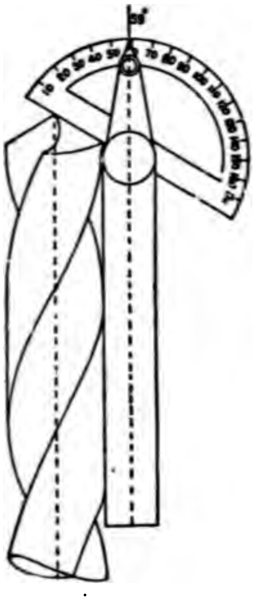


Fig. 29.

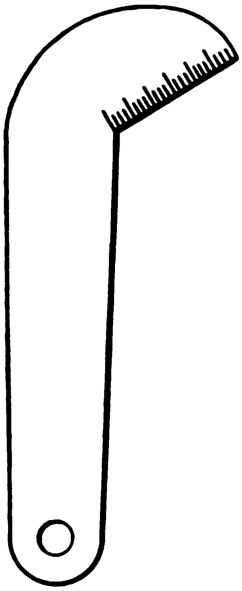


Fig. 30.

Grinding Twist Drills. The cutting edges must make a proper and uniform angle with the longitudinal axis of the drill; they must be equal in length, and the lips of the drill sufficiently backed off for clearance, otherwise they will not cut easily, or they will make a hole *larger* than the size of the drill.

Drills properly made have their cutting edges straight when ground to a *proper* angle, which is 59 degrees, as in Fig. 29. Grinding to an angle less than 59 degrees leaves the lip hooking, which is likely to produce a crooked and irregular hole.

A very satisfactory form of angle gauge for this work is shown in Fig. 30; the graduations on the upper part of gauge show when the lips are ground to an equal length, which is essential in order that the drill shall cut the proper size. As the operator becomes experienced he can gauge the angle and length of lips very accurately by the eye, but until he has the necessary experience it is advisable to use some form of gauge.

REAMERS.

A reamer is a tool that makes a smooth, accurate hole; however, in many cases reamers are used to enlarge a cored hole, or a hole already drilled, without particular reference to the exact size or condition of the hole. Reamers may be classified according to shape as follows: straight reamers, taper reamers, and formed reamers. Reamers are made solid, adjustable, and with inserted blades.

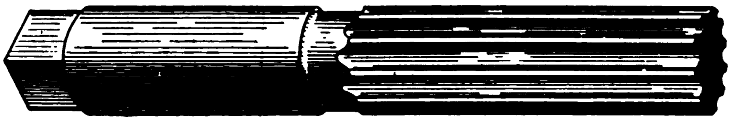


Fig. 31.

Solid reamers (Fig. 31) are so called because the cutting teeth and head are made from one piece; they have no means of adjustment as to size. The cutting teeth of inserted blade reamers are made from separate pieces of steel, and inserted in the head as shown in Fig. 32. The adjustable reamer may be made with inserted teeth, or with cutting teeth solid with the head; but in either case having some means of adjusting the size.

STRAIGHT REAMERS.

Under this heading the following kinds of reamers are to be found: fluted hand reamers, fluted chucking reamers, rose reamers, single lip reamers, and three and four lipped roughing reamers.

The Fluted Hand Reamer is made straight on the cutting lips, with the exception of a short distance at the end (A Fig. 33) which is slightly tapered in order that the reamer may enter the hole. In making such reamers, use steel from $\frac{3}{32}$ inch to $\frac{1}{8}$ inch above finish size. Turn a chip off the outside surface to a depth of $\frac{1}{32}$ inch and anneal, then turn A and B Fig. 33 to sizes .010 to .015 inch larger than finish size; turn C to finish size, mill the end D square for a wrench. The reamer is now ready to have the flutes cut.

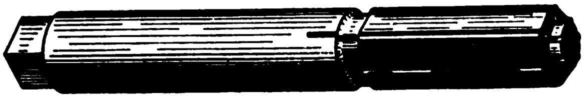


Fig. 32.

Number of Cuttting Edges. Fluted reamers designed to remove but a small amount of stock, and intended to cut holes to an accurate size are rarely given less than six flutes.

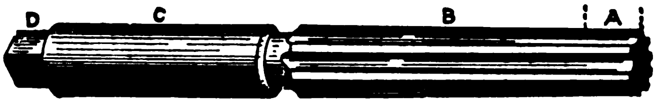


Fig. 33.

The following table gives the number of cutting edges that give satisfaction for solid reamers whose flutes are milled by cutters made to give the proper shape.

TABLE OF CUTTING EDGES FOR REAMERS.

$\frac{1}{8}$" to $\frac{7}{16}$" diameter	6 teeth
$\frac{1}{2}$" to $\frac{11}{16}$" "	6 to 8 "
$\frac{3}{4}$" to 1" "	8 "
1$\frac{1}{16}$" to 1$\frac{1}{2}$" "	10 "
1$\frac{9}{16}$" to 2$\frac{1}{8}$" "	12 "
2$\frac{1}{4}$" to 3" "	14 "

Formerly it was considered necessary to have an odd number of cutting edges; but an even number if unevenly spaced will be as satisfactory. The chief objections to an odd number are the difficulty experienced in calipering unless a ring gauge is used, and the great cost of grinding.

Fig. 34 shows a form of cutter that makes a strong reamer tooth and allows the chips to be removed very readily. These cut the tooth ahead of the center, and should be given a negative rake of about 5°. In general, a reamer will cut more smoothly if the tooth has a slight negative rake, as it then takes a scraping cut.

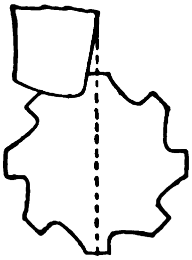


Fig. 34.

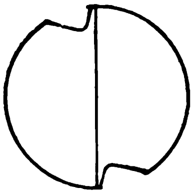


Fig. 35.

With this form of flute, the depth of cut must be so gauged that the land will be about 1/6 the average distance from one cutting edge to the other; if cut deeper, the teeth will be weak and have a tendency to spring, if not as deep, there will not be room for the removal of the chips. The following table shows the number of cutter (shown in Fig. 34) for any size of reamer.

NUMBERS OF CUTTERS FOR REAMERS.

No. 1	Cutter	cuts	reamers	from	1/8" to 3/16"	diameter.
No. 2	"	"	"	"	1/4" to 5/16"	"
No. 3	"	"	"	"	3/8" to 7/16"	"
No. 4	"	"	"	"	1/2" to 11/16"	"
No. 5	"	"	"	"	3/4" to 1"	"
No. 6	"	"	"	"	1 1/16" to 1 1/2"	"
No. 7	"	"	"	"	1 9/16" to 2 1/8"	"
No. 8	"	"	"	"	2 1/4" to 3"	"

In order that reamers may be calipered readily when grinding — if the teeth have been unevenly spaced — the teeth must be diametrically opposite each other; the unevenness in spacing must removed from the hardening bath when it stops *singing*, and plunged into oil, and allowed to remain until cold. The temper may be drawn to a light straw color.

If reamers are hardened by the "Pack Hardening" process, the danger of springing is greatly reduced.

Straightening Reamers. If a reamer springs while hardening and tempering, it may be straightened by the following method: Place the reamer between the centers of the lathe; fasten a tool, or piece of iron or steel having a square end in the tool

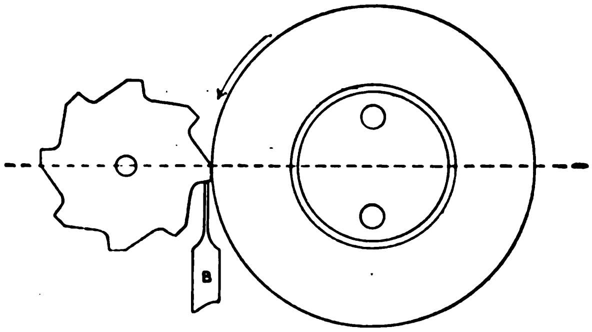
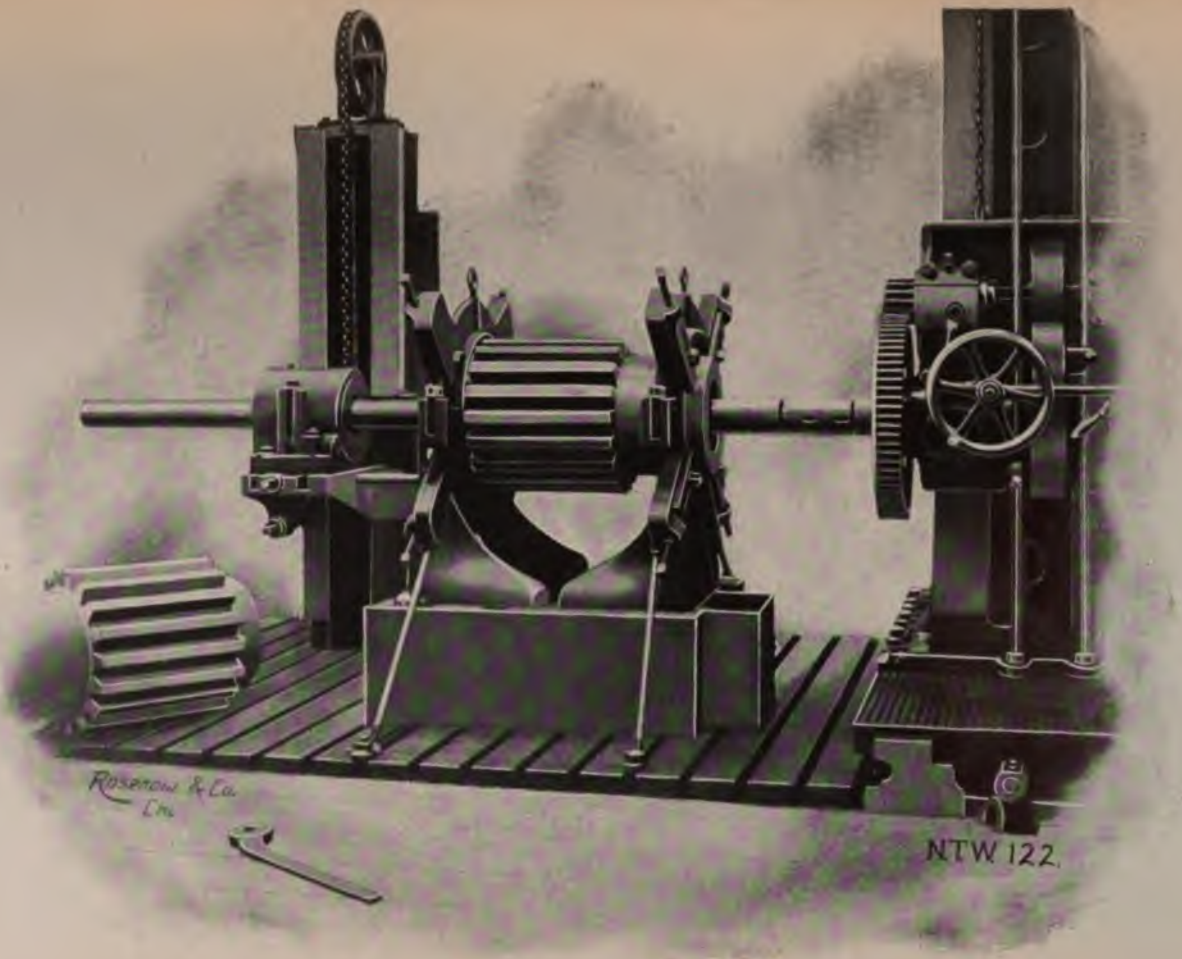


Fig. 37.

post (Fig. 36), placing the square end against the reamer at the point of greatest curvature. The surface of the reamer should be covered with a thin coating of sperm, or lard oil. With a spirit lamp, a plumber's hand torch, or a Bunsen burner, heat the reamer evenly until the oil commences to smoke; pressure may now be applied by means of the cross-feed screw, slowly forcing the reamer over until it is bent a trifle the other way. It should be cooled evenly while in this position. After it is cool the pressure may be relieved and the reamer tested for truth. If it does not run true the operation may be repeated. This method of straightening is equally effective when applied to other classes of work.

The straightening should be done before drawing the temper. When drawing the temper the heat should be applied evenly or the piece will spring from uneven heating.

Before *grinding a reamer* be sure that the centers of the grinding machine are in good shape, then clean the centers of



BORING LARGE PINION HELD IN STEADY REST.
Niles-Bement-Pond Co.

the reamer. The reamer should first be ground to run true. It may be ground to within .001 or .002 inch of finish size; large reamers having the greater amount. In backing off a reamer tooth for clearance use an emery wheel of as large diameter as possible without striking the cutting edge of the next tooth. The correct clearance is given by a finger which can be adjusted. Fig. 37 shows an end view of reamer being ground for clearance together with the finger and emery wheel. The emery wheel should run in the direction indicated by the arrow, in order that the pressure of the wheel will tend to force the reamer tooth down on the finger B. To give clearance, the finger is adjusted so that the cutting edge is below the line of centers as shown. The lower the finger the greater the amount of clearance. Unless a free cutting wheel, free from glaze is used the temper will be drawn, thus rendering the reamer worthless. To avoid softening the teeth, the stock must be removed by a succession of light cuts going way around the reamer each time the adjustment is changed.

A reamer will soon lose its size if the clearance is ground to the edge of the teeth; consequently it is best to grind to within from .01 to .015 inch of the edge, according to the size of the reamer. The reamer is then brought to an edge and to the desired size by oilstoning. To do satisfactory work the stone should be free cutting. Select a stone of medium grade for removing the stock, and use a "fine" stone for finishing the cutting edge. An oilstone should *not* be used dry; keep the face free from glaze. If there are deep depressions or marks in the stone, face it off on a wet grinding machine.

Fluted Chucking Reamers. The same general instructions given for making fluted-hand reamers, can be applied to this form; except that the shank may be finished to size before the reamer is hardened, unless the shank is to fit a collet or be held in a chuck.

The regular jobbing reamer used in the lathe is shown in Fig. 38; the form for the chucking lathe or drill press, where the shank is held in a collet or chuck is shown Fig. 39. When making this style of reamer, B may be left .010 to .015 inch above size to allow for grinding. The portion C may be finished to size and the dimension of the cutting part of the reamer stamped on it as shown; if the reamer is made for special work and is to be used on no other, the name of the piece, or operation it is intended for should also be stamped.

On account of the uncertainty of a reamer cutting exactly to size when used in a lathe, chucking reamers are frequently made somewhat under size. Standard *hand* reamers are used for finishing. The amount of stock left for the hand reamer varies: some tool makers consider .005 inch the proper amount for all reamers up to 3 inches in diameter; while others think that for 1 inch or less diameter .004 inch is right; and for sizes from $1\frac{1}{16}$ inches to 2 inches, .007 inch should be allowed. For reamers larger than 2-inch diameter an allowance of .010 inch should be made. The exact amount necessary for finishing with hand reamers depends on the nature of the work and the stock operated on. Fluted chucking reamers are made with either straight or spiral flutes.

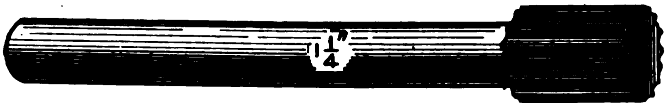


Fig. 39.

When a reamer is used in a screw machine or turret lathe, on work where accuracy and straightness of hole is essential, it should be held in some form of special holder, which allows it to properly locate itself as to alignment. Such holders will be described later under the heading "Reamer Holders."

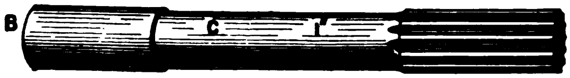


Fig. 39.

Rose Reamers. This form of reamer has its cutting edges only on the end as shown in Fig. 40, the grooves being cut the entire length of body to reduce the amount of frictional-bearing surface and to furnish a channel to conduct the lubricant to the cutting lips. In case there are blow holes or other imperfections in the material being operated on, this reamer will cut a more nearly parallel hole than the fluted chucking reamer.

Fig. 40 shows the ordinary form of rose chucking reamer. The shank B is turned to finish size; in case it is to fit a holder it is left slightly larger and turned or ground to size after hardening. The body A is turned .015 to .020 inch above finish size, the flutes cut, the size stamped as shown, and the reamer hardened a little above the body. It is customary when grinding a rose reamer to make it a trifle smaller on the end of body next to the shank; a taper of $\frac{1}{4000}$ inch in the length of the cutting part gives good results.

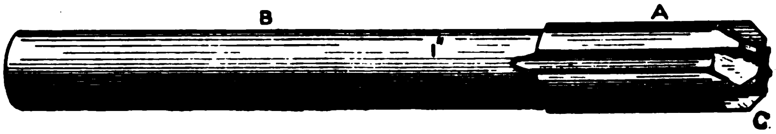


Fig. 40.

Small rose reamers can be made of drill rod, which runs very true to size, if ordered by the decimal equivalent rather than by the drill gauge number, or in terms of common fractions. For instance, if drill rod is wanted of a size corresponding to No. 1 Browne & Sharpe drill gauge, the wire will come much more accurate if ordered .228 inch diameter rather than by the gauge.

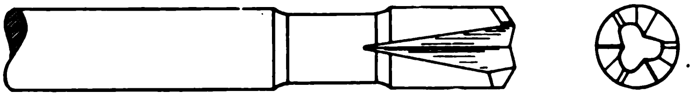


Fig 41.

The wire may be sawed to length, put in lathe chuck, and cornered for the cutting lips. When making small reamers that are not to be ground to size after hardening, it is advisable to neck them down back of the cutting edge, as shown in Fig. 41. The drill rod often swells or expands at a point where the hardening ends, and by necking down and hardening into the necking this difficulty is overcome.

Small rose reamers may be given three cutting edges. The flutes may be filed with a three-square or a round-edge file. If a three-square file is used, a groove of the form shown in Fig. 41 may be made. This has a tendency to push the chips ahead when cutting, while a groove filed with a round-edge file, if it be of a spiral form, will draw the chips back into the flute, provided it is a right-hand helix, as shown in Fig. 42.

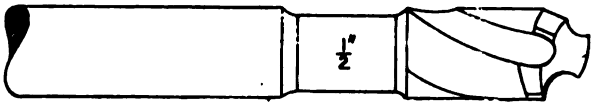


Fig. 43.

Rose reamers intended for reaming holes of exact size must be ground to correct dimensions after hardening, but small reamers intended for reaming holes where *exactness* of size is not essential may be made to size before hardening, and the cutting edges backed off with a file for clearance. If reamers are ground on the circumference for size, the lips or cutting edges should be

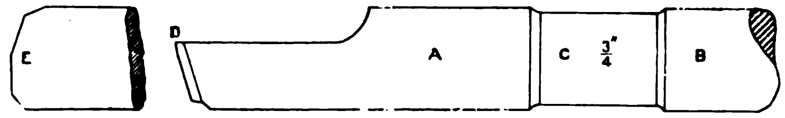


Fig. 43.

given clearance by grinding. After grinding, the corners of the cutting edges next to the body of the reamer, as shown at C, Fig. 40, should be rounded by oilstoning.

A Single Lip Reamer is very useful for reaming a *straight* hole. When the nature of the hole or the condition of the stock would cause the ordinary forms to *run*, the single lip reamer will cut a straight hole if started right. Having but one cutting lip, its action is similar to a boring tool used for internal turning in the lathe, and as a large proportion of the body of the reamer acts as a guide, it must cut a straight hole. Fig. 43 shows two views of this form of reamer.

Steel for this reamer should be sufficiently large to allow the decarbonized surface to be entirely removed. After a roughing chip has been taken,— leaving the piece about $\frac{1}{16}$ inch above finish size,— the stock should be annealed, after which the portions A and B should be turned to a size that allows for grinding. C may be finished to dimensions given, and the size of the reamer stamped as shown.

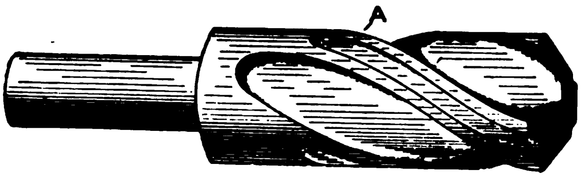


Fig. 44.

The reamer is now ready for milling. This should be done with the reamer in the centers in the milling machine, using a shank mill or a small milling cutter on an arbor. The depth of the cut should be about one-third the diameter of the reamer; for large reamers it may be somewhat deeper. After milling, the face may be smoothed with a fine file, and the end and cutting lip backed off for clearance, as shown in Fig. 43 at D and E.

When hardening, the end A should be heated to a low red and dipped in the bath about one-half an inch on the necked portion C. The temper may be drawn to a light straw. A and B are now ready for grinding. If the grinder has no provision for water to run on the work, care should be used not to heat the reamer, as it is likely to spring.

Three and Four Lipped Roughing Reamers are used to advantage in chucking machines for enlarging cored holes, or holes that have been drilled smaller than the required size. This is often done in making large holes in solid stock, as most manufacturers consider it more economical to use a smaller drill and a roughing reamer in order to bring them to proper size for the final reamer. Fig. 44 shows a reamer of this description.

The instructions already given for making the various reamers may be followed for this form, with the exception of cutting the grooves, which should be of a sufficient size to hold the chips. The small groove cut in the center of the lands is to feed oil to the cutting edges when cutting steel. When cast iron is the material to be operated on, the grooves are cut straight and the oil groove omitted. If a finish reamer is to be used in sizing the holes, it is customary to make the roughing reamer $\frac{1}{64}$ inch smaller than finish size. On account of the rough usage, great care should be exercised in hardening. While satisfactory results may be obtained by heating to a *low* red, plunging in a bath of brine, and drawing the temper to a light straw, the tools will do a great deal more if they are pack hardened by the process already described.

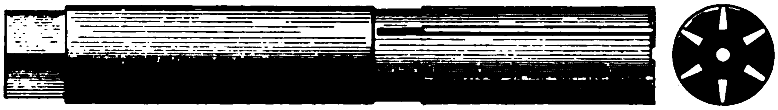


Fig. 45.

Inserted Blade Reamers. The particular advantage of solid reamers with inserted teeth is that when worn, new blades may be put in at a cost much less than that of a new solid reamer. Inserted blade reamers are usually made in such a manner that the size may be altered; in such cases they are termed expanding reamers. A simple form is shown in Fig. 45. The slots for the blades are milled somewhat deeper at the front end than at the end toward the shank; they are also somewhat wider at the bottom than at the top. The first is accomplished by depressing the spiral head a trifle, while the latter is done by first milling the slots with a cutter a little narrower than the top of the slot wanted, then turning the spiral head enough to produce the desired angle on one side of slot as shown at A in Fig. 46. The object in making

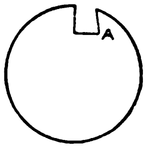


Fig. 46.

the slot deeper at the front end is that the blades, as they become dulled (and consequently cut small), may be driven farther into the body. As the slot is shallower, the blade is forced out as it advances, thus increasing its diameter; it may then be sharpened by grinding to size. The side of the slot is cut at an angle to hold the blade solidly and prevent any tendency it might have to draw away from its seating when the reamer is cutting. The body of the reamer is not hardened; the blades are machined to size, hardened, driven into place and ground to size. If the reamer is of the form known as *fluted reamer*, the teeth may be backed off for clearance as already described.

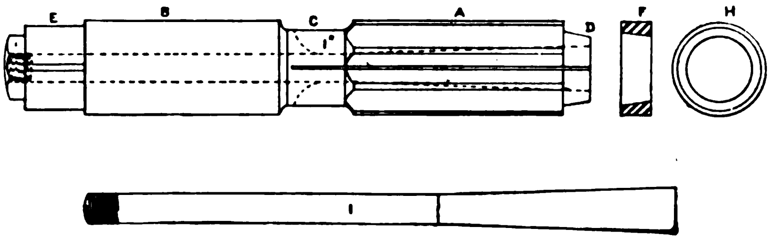


Fig. 47.

Adjustable Reamers are made of a form that allows them to be adjusted to a varying size of parts of machines where interchangeability is not essential. Fig. 47 shows the cheapest form of adjustable reamer; this form is sometimes objected to because it does not expand or contract uniformly its entire length; for ordinary work, however, it is very satisfactory, if used for a limited range of sizes.

Stock should be selected at least $\frac{3}{32}$ inch larger than finish size. After carefully centering and squaring the ends, a chip should be turned the entire length of the piece. It should then be drilled, and the taper hole reamed for the expansion plug. When drilling the outer end, the blank should run in the steady rest; the hole in the *shank* end should be drilled to the proper depth with a drill $\frac{1}{32}$ inch *larger* than the straight stem of the expansion plug. The end should be chamfered to a 60° angle to run on the lathe center when turning and grinding. The piece may be reversed and the opposite end drilled and reamed with a taper reamer; this end should be chamfered also to a 60° angle. Fig. 48 shows a sectional view of the blank drilled and reamed, and the ends of the hole beveled.

The reamer may now be turned .020 to .025 inch above finish sizes on A and B, while C and D may be turned to finish sizes, and the size stamped at C. The end E may be milled square for a wrench, the grooves milled and the reamer split, in order that the size may be altered with the expansion plug.

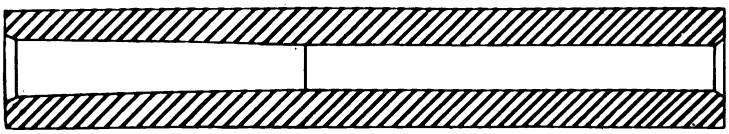


Fig. 48.

When splitting the reamer, a metal slitting saw of the required thickness (usually $\frac{1}{16}$ inch) should be used. The saw cut should not extend to the end of the reamer, but a small portion should be left solid to prevent the reamer from springing when hardening. The circular saw leaves a cut at the end of the shape shown in Fig. 49, which would be extremely difficult to part after hardening. In order that the thin partition of stock may be easily severed with an emery wheel, the slot may be finished, as shown in Fig. 50, with a hand hack saw.

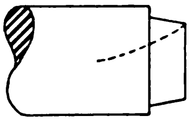


Fig. 49.

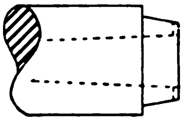


Fig. 50.

The expansion rod I, Fig. 47, should be turned to fit the taper in the reamer, the straight end should be $\frac{1}{32}$ inch smaller than the hole running through the reamer, and should be threaded on the end for a nut to be used in drawing the rod into the reamer. The collar shown at F and H should have a taper hole tted to the tapered end of the reamer. The outside diameter of llar should be a trifle smaller than the hole to be reamed; this collar, when forced onto the end of the reamer, holds it in place. In order to increase the size of the reamer, the collar may be driven back a trifle and the rod drawn in by means of the nut.

After the reamer is hardened and tempered, the thin partitions left at the ends of the slots may be ground away with a beveled emery wheel, the rod inserted, the collar forced on the end, the reamer ground to size, and the teeth backed off for clearance.

TAPER REAMERS.

If a taper reamer is intended for finishing a hole, the same general instructions may be followed as for *fluted hand reamers*, except that instead of being straight, the body, or cutting part, is tapered.

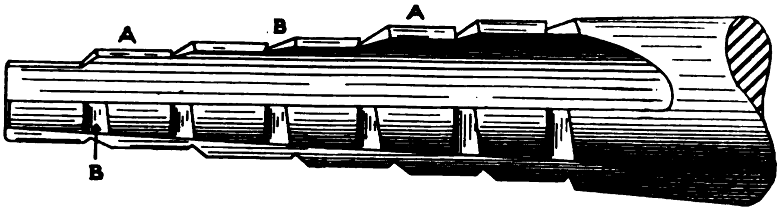


Fig. 51.

Roughing taper reamers are frequently made in the form of a stepped reamer, or it might be called a multiple counterbore, since each step acts as a pilot for the next larger step, as shown in Fig. 51. The steps A are turned straight, each one correspondingly larger than the preceding. The cutting is done at the end of the step B, which must be given clearance; this is ordinarily done with a file. The reamer may be given four cutting edges; these should be cut with a milling cutter intended for milling the flutes of reamers. The number of the cutter selected will depend on the form and amount of taper of the reamers. It is advisable to neck down into the reamer $\frac{1}{32}$ inch at the end of each step; this may be done with a round nose tool, or a cutting-off tool having its corners slightly rounded. The necking facilitates the filing of the cutting edges, and also allows the emery wheel to traverse the entire length of each step when grinding to size after hardening.

Roughing reamers are sometimes made of the form shown in Fig. 52. The left-hand thread cut the entire length of the cutting portion breaks the chips into short lengths, and greatly increases the cutting qualities. After turning the tapered part to a size that allows for grinding, the lathe may be geared to cut a four-pitch thread. The threading tool should be about $\frac{1}{16}$ inch thick at the cutting point, and have sufficient clearance to prevent the heel dragging when the tool is cutting. The corners should be slightly rounded in order to reduce the tendency of cracking when the reamer is hardened. The thread should be cut to a depth of from $\frac{1}{64}$ to $\frac{1}{32}$ inch. After threading, the flutes may be cut, the reamer hardened, and the temper drawn to a light straw.

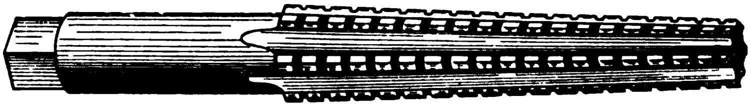


Fig. 52.

When grinding a *taper reamer* the proper clearance is given to the tooth back for a distance of $\frac{3}{64}$ inch from the cutting edge, the balance of the tooth is given a greater amount of clearance, as shown in Fig. 53.

Shell Reamers. As a matter of economy, the larger sizes of reamers are sometimes made in the form of shell reamers, as shown in Figs. 54 and 55. As several reamers may be used on the same arbor, there is quite a saving in cost of material.

The following table gives the size and length of shell reamers from one inch to three inch diameter, together with the size of holes, and width and depth of tongue slot.

			Tongue Slot.	
Diameter.	Length.	Size of Hole.	Width.	Depth.
1″ to $1\frac{1}{4}$″	$2\frac{3}{4}$″	$\frac{5}{8}$″	$\frac{1}{4}$″	$\frac{1}{4}$″
$1\frac{5}{16}$″ to $1\frac{5}{8}$″	3″	$\frac{3}{4}$″	$\frac{5}{16}$″	$\frac{3}{16}$″
$1\frac{11}{16}$″ to 2″	$3\frac{1}{4}$″	1″	$\frac{3}{8}$″	$\frac{5}{16}$″
$2\frac{1}{16}$″ to $2\frac{1}{2}$″	$3\frac{3}{4}$″	$1\frac{1}{4}$″	$\frac{1}{2}$″	$\frac{3}{8}$″

After drilling a hole $\frac{1}{16}$ inch smaller than finish size, the blank should be placed on a mandrel and a heavy chip taken to remove all the original surface. It should then be annealed.

After annealing it may be placed in a chuck on the lathe and the hole bored .005 inch smaller than finish size. After putting on a mandrel, the ends should be faced to length and the outside diameter turned, leaving .010 to .015 inch on the cutting part for grinding. The balance of reamer should be turned to size. If it is to be a *rose reamer* the edge should be chamferred the proper amount.

The reamer should be held in a chuck on the spiral head spindle in the milling machine, and the tongue slot cut. In order to get the slot central with the outside of the reamer, a cutter somewhat narrower than the desired slot should be used, which should be set as centrally as possible by measurement, a cut taken, the spiral head turned one-half way round and another cut taken; the width of the slot should be measured, and the saddle of the machine moved by means of the graduated adjusting screw one-half the amount necessary to make the slot of the right width. The reamer may now be placed on a mandrel between centers on the milling machine, and the grooves cut.

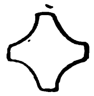


Fig. 53.

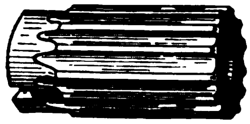


Fig. 54.

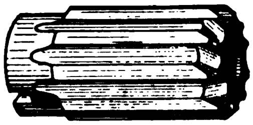


Fig. 55.

The reamer should be heated for hardening in some receptacle in order that the fire may not come in direct contact with it; when it reaches a *low uniform* red heat it may be placed on a wire bent in the form of a hook, and plunged in the bath; it should be worked up and down rapidly until all trace of red has disappeared. When cold it may be heated to prevent cracking from internal strains; if it is to be a rose reamer it may be left *dead* hard, if a fluted reamer the temper should be drawn to a straw color. The hole should be ground to fit the shank on which it is to be used, or a plug gauge, if there is one for the purpose. The reamer may then be placed on a mandrel and ground according to directions given for grinding reamers.

The holes in *shell reamers* are sometimes made tapering — the end of the arbor being made of a corresponding taper — to avoid the necessity of grinding the holes, as any slight change in the size resulting from hardening would be compensated for by the taper hole.

Arbors for Shell Reamers are made as shown in Fig. 56 The shank B and end A to receive the reamer, are made in one piece. The collar C having two tongues to engage in the slots in the reamer, is made of tool steel; the hole is made of a size that allows it to slide over A. When in position a hole is drilled through both collar and arbor and the pin D driven in. When making the collar the hole is drilled and reamed; it is placed on a mandrel, the ends faced to length, and the collar turned to proper diameter. It is then removed from the mandrel and the tongues milled. While doing this the collar is held in the chuck on the spindle of the spiral head and a side milling cutter is used. One side is milled, the spiral head spindle turned one-half revolution, and the opposite side milled; the thickness is measured and the saddle moved enough to bring the tongues to the required thickness when the finish cut is taken on each side. After putting on an arbor and drilling the pin hole, the collar may be removed and spring tempered. It may now be placed on the arbor and the pin driven in place.

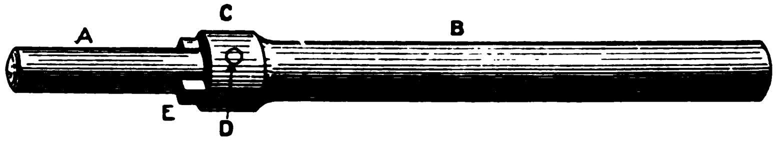


Fig. 56.

When the hollow mill is made with a taper hole, the arbor is made with the end A of a corresponding taper. Otherwise the construction would be the same as for hollow mills having straight holes.

Formed Reamers are used for holes of an irregular shape, or rather of a shape neither straight nor tapering. They are used chiefly by gun makers in reaming the end of the gun barrel for the shell, and are termed, when used for this class of work, *chambering reamers.*

It is essential when making this class of reamer, that the stock be rough turned a little above finish size and then annealed. Reamers of this form are accurate as to size and shape, consequently it is customary to use a gauge. This is generally a piece of steel having a hole of the proper form reamed in it, after which the stock is cut away on one side, leaving a trifle more than one-half of the hole as shown in Fig. 57.

To make the reamer blank fit the gauge the operator must understand the use of hand turning tools, as most shapes must be made with these tools. The teeth must be cut with a milling cutter of small diameter following the different shapes of the reamer in order to have the top of the land of as uniform a width as possible. After cutting, the teeth may be backed off for clearance with a file, taking care not to remove any stock at the cutting edge.

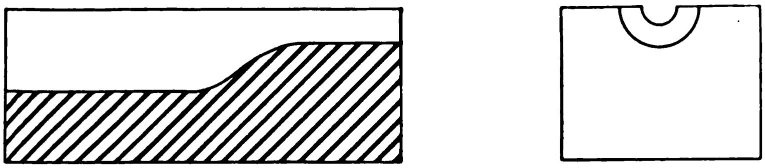


Fig. 57.

When hardening, heat very carefully in a tube until the reamer is of a *low* uniform red heat; it should then be plunged in a bath of lukewarm brine. It may be brightened and the temper drawn to a light straw. After hardening it should be tried in the gauge, and any high spots removed by oilstoning.

If a large number of reamers of one form are to be made, the grinding machine may be rigged with a form which makes it possible to grind many of the shapes in common use, but some shapes will be found quite impracticable to grind, consequently the above method of fitting before hardening must be adopted. Excellent results are obtained by hardening by the "Pack Hardening" process.

Reamer Holders. On account of the uncertainty of exact alignment of every part of a screw machine or turnet lathe, it is desirable to use a holder for the reamer that allows it to properly align itself. The form of holder shown in Fig. 58 is in common use and gives excellent results. It consists of the body A which has a hole drilled and reamed its entire length; the hole must be somewhat larger than the shank of the reamer, $\frac{1}{16}$ inch being considered sufficient. The center B of tool steel should be (after hardening) .010 to .015 inch larger than the hole in the holder; the point should be ground to a 60° angle, and the straight part ground to a forcing fit in the holder. After being forced to position a hole may be drilled through the holder and center, and the pin C driven in to keep the center from being pressed back by the reamer when in operation. A pin should be put through the holder at D; a hole $\frac{1}{16}$ inch larger than the pin should be put through the reamer shank at this point. This pin is simply to prevent the reamer from turning when it comes in contact with the work. The coil springs E E hold the reamer in position to enter the hole, and the proper tension is given by means of the screws F F.

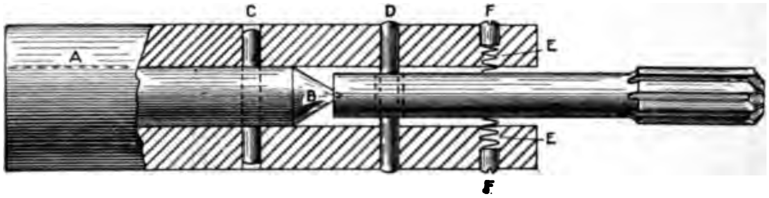


Fig. 58.

ARBORS.

Mandrels. The ordinary taper arbor, known as the mandrel, is in common use in most machine shops. Up to and including $1\frac{1}{2}$ inches diameter, mandrels are made of tool steel, hardened all over and ground to size. Some tool makers advocate making all mandrels up to 4 inches diameter in this way; others prefer hardening the ends B B (Fig. 59), leaving the center A soft, while others maintain that for mandrels above $1\frac{1}{2}$ inches diameter, machinery steel is most satisfactory if thoroughly case hardened.

When making mandrels of tool steel that are to be hardened the entire length, it is not necessary to use the best quality of steel, as a lower grade may be used if it will harden well. Select stock somewhat larger than finish diameter, say $\frac{1}{16}$ inch for sizes up to $\frac{1}{2}$ inch; $\frac{1}{8}$ inch for sizes up to 1 inch; $\frac{3}{16}$ inch for sizes up to $1\frac{1}{2}$ inches, and $\frac{1}{4}$ inch for sizes above. Take a chip off the outside sufficiently heavy to remove all scale, yet leaving $\frac{1}{32}$ inch for a finish cut on sizes up to $\frac{1}{2}$ inch and correspondingly more for the larger sizes. It should now be annealed, preferably in the annealing box. The ends should be countersunk deeper in mandrels than in tools where the centers are not used after they are completed, in order that the centers may not be mutilated when driven in or out of the work. The centers should either have an extra countersink, as at A in Fig. 60, or else the cut should be recessed as at B in Fig. 61.

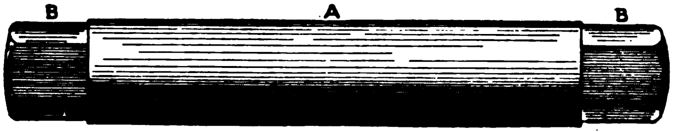


Fig. 59.

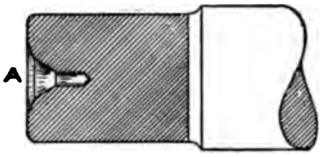


Fig. 60.

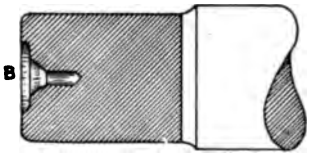


Fig 61.

The ends B B, Fig. 59, should be turned to size, the corners slightly rounded, and the flat spots for the dog screw milled or planed. The body of the mandrel should be turned somewhat larger than finish size; those smaller than $\frac{1}{2}$ inch should have an allowance of .015 inch; from $\frac{1}{2}$ to 1 inch an allowance of .020 to .025 inch; over 1 inch an allowance of .025 to .030. As tho length of mandrels larger than 2 inches diameter does not increase in proportion with the diameter, the amount given will generally be sufficient if proper care is used when hardening. The size should be stamped on the end next to the large end of body.

Before hardening, the centers should be re-countersunk to true them; for this operation it is best to use a special countersink having an angle of 59° instead of the regular 60° tool, as it facilitates the lapping of the centers to a 60° angle after hardening, due to the unequal amount of grinding caused by the shape of the countersinking.

If a blacksmith's forge must be used when heating the mandrel for hardening, the fire should be large enough to heat the piece evenly; it is advisable to heat it in a tube. More uniform results can be obtained from a muffler furnace than in the open fire. In either case the piece should be turned frequently, to insure an even heat. To dip in the bath, a pair of tongs of the shape shown in Fig. 62 should be used, so that the bath may come in contact with both centers. The tongs should grapple the mandrel at the large end, in order that the small end may be harder; it should be worked up and down rapidly in the bath to insure uniform results. A bath of brine will be found very satisfactory for this work.

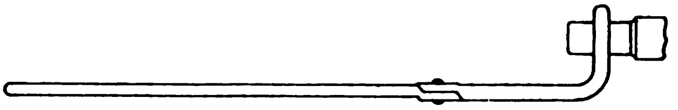
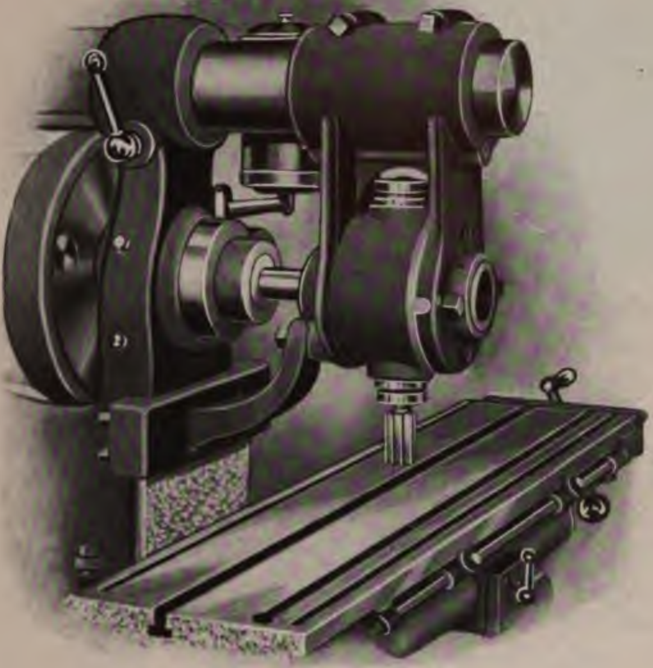


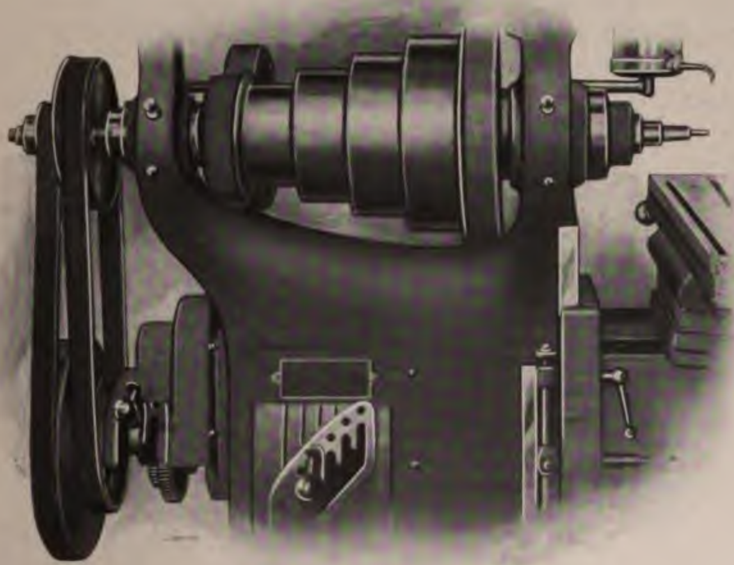
Fig. 52.

A mandrel larger than 1 inch diameter should be removed from the bath as soon as it ceases *singing*, and held in a tank of oil until cold. The ends should be brightened and drawn to a deep straw color, in order to toughen them so that they will not break or chip off when driven. Mandrels smaller than ¾ inch should have the temper drawn to a light straw color the entire length of body.

After hardening, the body of the mandrel should be cleaned with a coarse emery cloth, to remove the scale or grease which



VERTICAL SPINDLE ATTACHMENT.



HIGH-SPEED ATTACHMENT.
Hendey Machine Co.

would glaze the emery wheel. It should then be tested between centers to see if it has sprung more than will grind out before it reaches the proper size.

The centers should now be lapped, to insure proper shape and alignment. The lap may be a piece of copper of the proper shape (60°) charged with diamond dust or emery. After lapping, the centers should be thoroughly cleaned with benzine. (When using benzine do not allow it to get near a flame of any kind.)

Examine very carefully the condition of the centers of the grinder, as the truth of the mandrel depends in a great measure on their condition. A mandrel may be ground in a lathe having a grinding attachment or in any universal grinder. Better results can be obtained, however, if ground in some form of grinder having a stream of water to keep the work from heating, as heat is likely to spring the piece, especially if it does not run true, thus making the grinding heavier on one side than the other. If a dry grinder must be used, do not force the grinding fast enough to heat the piece. The mandrel should be ground to within about .005 inch of size with a coarse wheel free from glaze, and then finished with a fine wheel.

The amount of taper varies: some manufacturers prefer .0005 inch taper per inch, while others make them of .001 inch taper for every inch of length, claiming that if a piece having a long hole is to be held on *any* taper mandrel it will not fit at the end nearest the small end of mandrel, consequently the turned surface will not be true with the hole; also that for such work a mandrel should be made for the job having a body nearly or quite straight. They claim that the mandrel should be made to taper .001 inch for every inch of length, in order that it may be adapted to a greater range of work.

Mandrels with Hardened Ends. When making a mandrel whose ends are to be hard and body soft, follow the instructions given for hardened mandrels, except that a larger amount of stock should be left on the body. The ends should be hardened for a distance that insures the *centers* being hard; this can be accomplished by heating one end at a time to a red heat, and inverting under a faucet of running water. As the center is uppermost, the water can readily enter it, forcing the steam away. After drawing the temper of the ends and lapping the centers, the body may be turned to size. The centers of the lathe should be carefully trued before starting this operation. If the body of the mandrel is left .008 inch to .010 inch larger after turning, and then ground to size, the results will be surer; but with *extreme care* a very satisfactory job may be done by the method described.

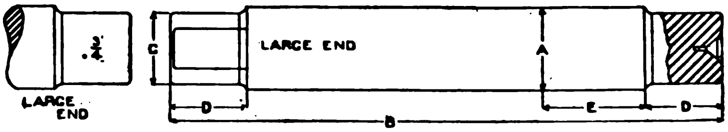


Table of Dimensions of Mandrels to 1 Inch.

A	B	C	D	E	F
$\frac{1}{4}$	$3\frac{3}{4}$	$\frac{7}{32}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{8}$
$\frac{5}{16}$	4	$\frac{9}{32}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{32}$
$\frac{3}{8}$	$4\frac{1}{4}$	$\frac{11}{32}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{16}$
$\frac{7}{16}$	$4\frac{1}{2}$	$\frac{13}{32}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{7}{32}$
$\frac{1}{2}$	5	$\frac{7}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{1}{4}$
$\frac{9}{16}$	$5\frac{1}{4}$	$\frac{1}{2}$	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{9}{32}$
$\frac{5}{8}$	$5\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{5}{16}$
$\frac{11}{16}$	$5\frac{3}{4}$	$\frac{5}{8}$	$\frac{13}{16}$	$\frac{15}{16}$	$\frac{11}{32}$
$\frac{3}{4}$	6	$\frac{11}{16}$	$\frac{7}{8}$	1	$\frac{3}{8}$
$\frac{13}{16}$	$6\frac{1}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{1}{16}$	$\frac{13}{32}$
$\frac{7}{8}$	$6\frac{1}{2}$	$\frac{13}{16}$	$\frac{15}{16}$	$1\frac{1}{8}$	$\frac{7}{16}$
$\frac{15}{16}$	$6\frac{3}{4}$	$\frac{7}{8}$	$\frac{15}{16}$	$1\frac{3}{16}$	$\frac{15}{32}$
1	7	$\frac{15}{16}$	1	$1\frac{1}{4}$	$\frac{1}{2}$

Machinery Steel Mandrels. With the exception of hardening, the instructions given for making mandrels of tool steel apply to those made of machinery steel. It is necessary to *case harden* mandrels made of machinery steel, using the method already described. The work should be run in the fire from seven to ten hours after the box is red hot throughout; dip in a a bath having a jet of water coming up from the bottom to force the steam away from the work, to avoid soft spots. It is not necessary to draw the temper, as the hardening does not extend far below the surface.

Expanding Mandrels. There are several forms of expanding mandrels in common use. One form has a sleeve with a taper hole fitting on a mandrel that has a corresponding taper; the sleeve is split to allow it to expand as it is forced on the mandrel.

It is not advisable to give the mandrel very much taper, because a heavy cut with the pressure toward the small end would crowd the sleeve toward that end, thereby releasing the work. Ordinarily a taper of ½ inch to the foot will give good results.

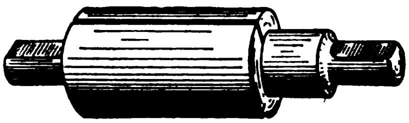


Fig. 63.

It is obvious that the range of adjustment for a sleeve as described is small, but sleeves of different diameters may be fitted to the same mandrel, the thickness of wall being increased to give the desired size. The diameter of the sleeve should be such that the work may enter without forcing, the tightening being accomplished by forcing or driving the sleeve toward the large end of the mandrel.

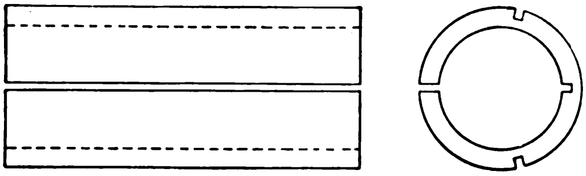


Fig. 64.

If a sleeve is required for a special sized hole, and is to be used but a few times, and through a limited range as to size, it may be made of cast iron. A hole is bored in it corresponding in size and taper to its mandrel; the hole should be made to allow the small end of the mandrel to go through and be flush with the end of the sleeve. The sleeve should be forced on the mandrel and turned to size; the outside diameter should fit the hole in the piece to be machined when the sleeve is at the small end.

In order that the sleeve may be expanded it is split as shown in Fig. 64. This should be done in the milling machine, the sleeve being held by the ends in the vise and the cut made with a metal slitting saw. When the sleeves are intended for permanent equipment it is good practice to make them of either machinery steel or tool steel,— if made of the former they may be case hardened, if of the latter they may be hardened and spring tempered. In either case the hole should be .010 inch small, and the outside diameter .020 to .025 inch large, and ground to size after hardening. A method of splitting the sleeve for a more uniform expansion is shown in Fig. 65; small sizes have four cuts for adjustment, while the larger sizes have six or eight.

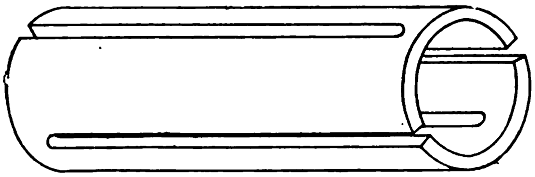


Fig. 65.

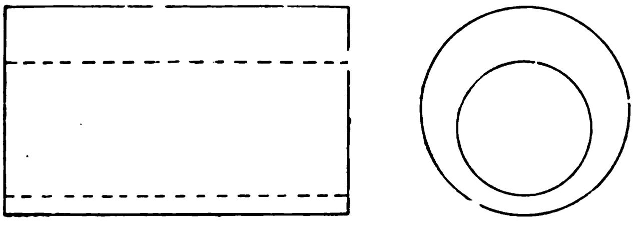


Fig. 66.

On account of the peculiar construction of the sleeve shown in Fig. 65 it must be held while grinding the hole, so that it will not spring. To do this the sleeve may be placed in a hole in a collar and held by several drops of solder so placed as to hold it rigidly in position. In order that the solder may stick, the outside of the sleeve must be brightened. When soldered securely the collar may be placed in the chuck on the grinding machine and the hole ground to the desired size, after which it may be heated to melt the solder, and the sleeve removed from the collar. It can then be placed on the mandrel and the outside diameter ground to the proper size.

Eccentric Arbors. Arbors are made eccentric in order that the outside of a piece of work may be made eccentric to the hole running through it, as shown in Fig. 66.

When making an eccentric arbor the general directions given for making mandrels may be followed, except that the centers should be quite small. The mandrel should be placed in a V block or in a pair of centers, and by means of a surface gauge, the needle of which has been set at the exact height of the center, a line may be drawn, as shown in Fig. 67, across each end of the mandrel. The mandrel may now be turned so that the line will be vertical; the point of the surface gauge may be raised to give the required amount of eccentricity, and a line, as shown in Fig. 68, scribed on each end. The ends should be prick punched where the lines intersect, and drilled and countersunk at this point.

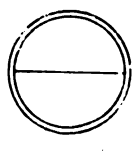


Fig. 67.

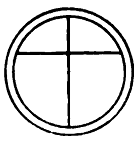


Fig. 68.

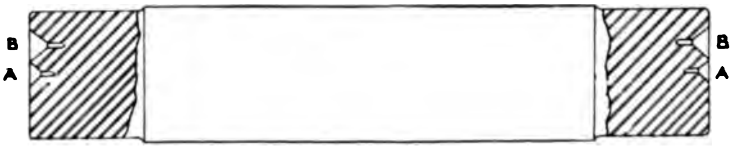


Fig. 69.

After hardening, both pairs of centers should be lapped to shape. The centers marked A A (Fig. 69) must be used when grinding the mandrel to size or in turning work which is to be concentric with the hole, while the centers B B are used when turning the eccentric parts. This method of laying off and drilling the eccentric center may not give the necessary accuracy; in such case a jig must be used in drilling the center holes. A suitable jig is shown in Fig. 70. The ends of the arbor must be turned to fit the hole A, Fig. 70, in the jig, which is a collar having a straight hole through it. A piece of steel, which is a forcing fit in this hole, has a hole the size of the centering drill laid off with the proper amount of eccentricity. This piece of steel is forced to the center of the collar, as shown at B. A straight line should be drawn across the collar and down the beveled edges, as shown at C. A line should now be scribed the entire length of the mandrel, which should be set to match the line on the jig, which may be secured in its proper position by means of the set screws.

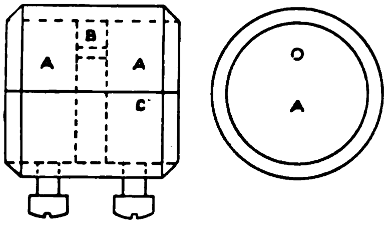


Fig. 70.

For machining a cylindrical piece having a hole through it to receive an arbor, and the faces of the piece not parallel, as shown in Fig. 71, it is well to use a mandrel having two sets of centers, as shown in Fig. 72, one of which, A A, are the regular centers, while the eccentric centers, B B, should be equidistant from the regular centers, but on opposite sides.

Milling Machine Arbors. Arbors for milling machines should be made from steel strong enough to resist (without twisting or springing) the strain caused by tightening the nut. When a limited number of arbors is made, tool steel is generally used: but for many milling machines, necessitating a great many arbors, a lower priced steel having the necessary stiffness is selected.

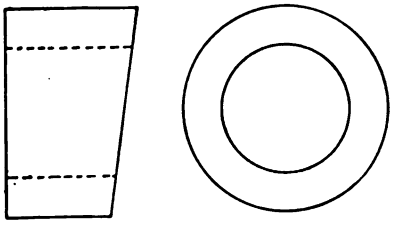


Fig. 71.

After centering and squaring the ends, a chip is turned the entire length of the piece, to remove all the outer surface. The ends D and C, Fig. 73, are next turned to size, and the tenon milled to the desired dimensions: when milling for the tenon, the arbor should be held between centers, and the cutting done with an end mill of the form shown in Fig. 74; the circumference of the cutter, leaving the proper shape at end of tenon. The centers should be hardened, and the temper drawn to a straw color. If the projection on the end of the arbor at C, Fig. 73, is to be run in a socket in the tail block of a milling machine, it must be hardened the entire length, in which case the thread for the nut should be cut before hardening the end. If a lathe having a taper attachment is used, there is no particular method of procedure other than that the arbor should be roughed nearly to size before either the taper or straight end is finished. It will save time, however, if the straight end A, Fig. 73, is roughed first, then the taper B roughed and finished, after which the shoulder E and the straight part A may be turned to size and finished. If the projection C is to run in a socket, it should be turned .010 or .015 inch above finish size, and ground to the proper dimensions.

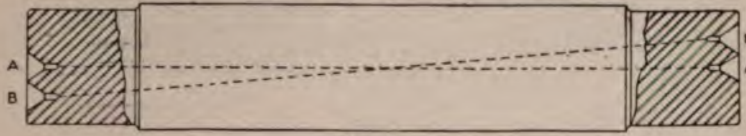


Fig. 72.

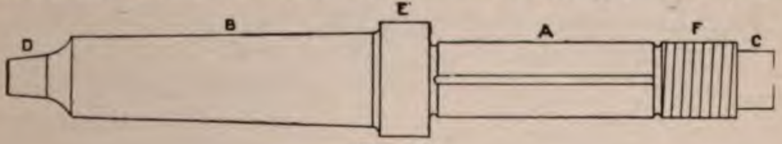


Fig. 73.

If it is necessary to use a lathe having no taper attachment, the necessary taper must be obtained by setting over the tail block. In this case it is better to turn and fit the taper first. If the taper were turned to finish size after finishing the straight part, the centers would become changed to a degree that would throw the arbor out of true. These instructions should be followed wherever a straight and taper surface are to be turned on the same piece of work, in a lathe having no other means of turning tapers except by setting over the tail block.

Milling machine arbors should have a spline slot cut the entire length of the part that is to receive the cutters; this can best be done in a shaper. Before putting the arbor in the shaper vise a hole should be drilled close to the shoulder for the tool to run into; the drill used should be about $\frac{1}{32}$ inch larger in diameter than the thickness of the splining tool, and the hole drilled a trifle deeper than the slot to be cut. When the arbor is placed in the vise a piece of sheet brass or copper should be placed between the arbor and the vise jaws to prevent bruising the arbor.

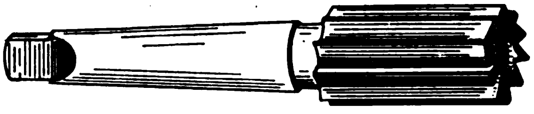


Fig. 74.

Where *extreme* accuracy is required, it is advisable to leave the straight and taper parts a few thousandths of an inch above size and grind to size all over after the spline cut is taken.

The nut is usually made of machinery steel, case hardened. A bar of steel $\frac{1}{16}$ inch larger than finish size of nut is selected, and a piece $\frac{1}{16}$ inch larger than finish length is cut; it is then put in a chuck on the lathe, the hole drilled, and the thread cut; if no tap of the desired size is at hand the thread may be chased. If a tap can be obtained, the thread should be chased nearly to size and finished with the tap; before taking from the chuck the end of nut should be faced and the hole recessed to the depth of the thread for a distance of two threads. After taking from the chuck it should be placed on an arbor having a screw which fits the thread in the nut. The nut should be turned to size and length, and the two opposite sides milled to receive the wrench used in tightening. Fig. 75 gives two views of the nut. It should be made and case hardened before the thread is cut on the arbor, in order that the thread on the arbor may be made to fit the nut. Milling machine arbor nuts should fit the thread on the arbor in such a manner that they may be turned the entire length of the thread without the aid of a wrench, yet not be loose.

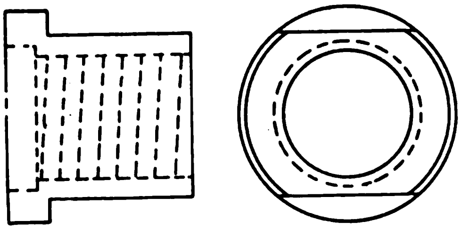


Fig. 75.

TAPS.

When making taps $\frac{1}{4}$ inch diameter and smaller, the threads are often cut with screw dies, of which there are two styles. The form of screw plate shown in Fig. 76 is termed a *jam die plate.* With this form the die is opened to allow the wire to pass through until it is even with the outside edge of the die, which is now forced into the wire by means of the adjusting screw A; the screw plate is revolved until a thread the desired length is cut. This operation is continued, the die being closed a trifle each time until the desired size is obtained. The method taken of gauging the correct size varies in different shops; if only one is made, the tops of the threads are measured with a micrometer caliper; but for many taps of the same size, such as for sewing machines, guns and bicycles, a sizing die is used to give the threads an exact size. The threads are cut to within a few thousandths of an inch with the die plate, and finished with the sizing die. One form of sizing die is shown in Fig. 77.

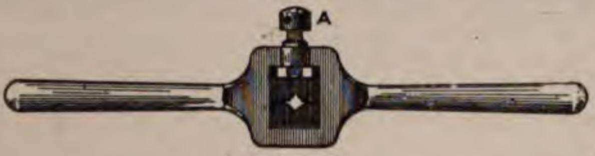


Fig. 76.

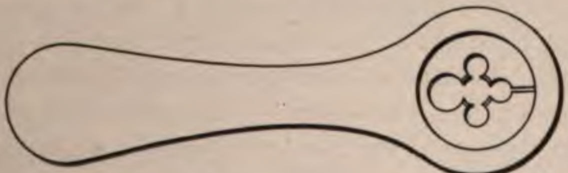


Fig. 77.

Where a great many taps of a size are cut, it is customary to use several dies of different sizes, one of which (the finishing die) is always made adjustable. The roughing dies may be made solid or adjustable, but the finishing must be adjustable for wear, or when it is found desirable to change the size of the taps. These dies are sometimes held in separate holders of the form shown in

Fig. 77, but a very convenient form of holder is shown in Fig. 78. If all the dies are in one holder they do not become scattered around the shop. When making many taps at a time, the work can be done better and cheaper if the wire is held in a chuck in a lathe. The die plate should be placed against a drill pad held in the tail spindle of the lathe, in order to insure starting the threads true. The largest die should of course be run on first, the second largest next and so on to the finish die.

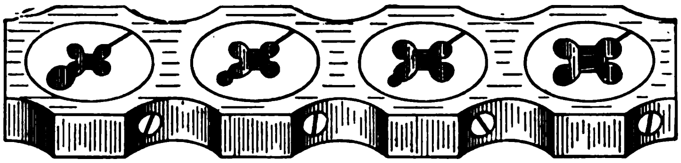


Fig. 78.

For taps up to and including $\frac{1}{4}$ inch diameter, it is customary to use drill rod. The taps should be chamferred for a distance of three or four threads, as shown at A, Fig. 79, in order that the point may enter the drilled hole.

Taps for general use around the shop are often made in sets of three; the first tap to enter the hole is called the taper tap, because of tne long chamferring or taper. The second is known as the plug tap; this tap has the first two or three end threads chamferred, and is used when the screw is to go nearly to the bottom of the tapped hole. The bottoming tap is used when the thread is to go to the bottom of the hole being tapped; the end of this tap is not chamferred. See Fig. 80.

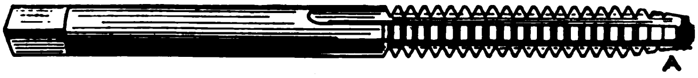


Fig. 79.

Taps larger than $\frac{1}{4}$ inch are made from tool steel. Taps $\frac{1}{4}$ to $\frac{1}{2}$ inch diameter should be made of stock at least $\frac{1}{16}$ inch large; it should be centered quite accurately with a small drill, because a large center hole weakens the tap and increases the liability of its cracking when hardened. After taking a chip sufficiently deep to remove all the outer coating, it should be "box anneale if possible.

HAND TAPS.

Hand taps are intended for tapping holes by hand and are usually made in sets of three, as previously explained. After annealing, the shank should be turned to size and the square end milled for a wrench. The body should now be turned to size, and the thread cut. Before turning any of the parts to size or starting to cut the thread, be sure that the centers of the lathe are in good condition; the live center should run true, the dead center should fit the center gauge, and be in good shape.

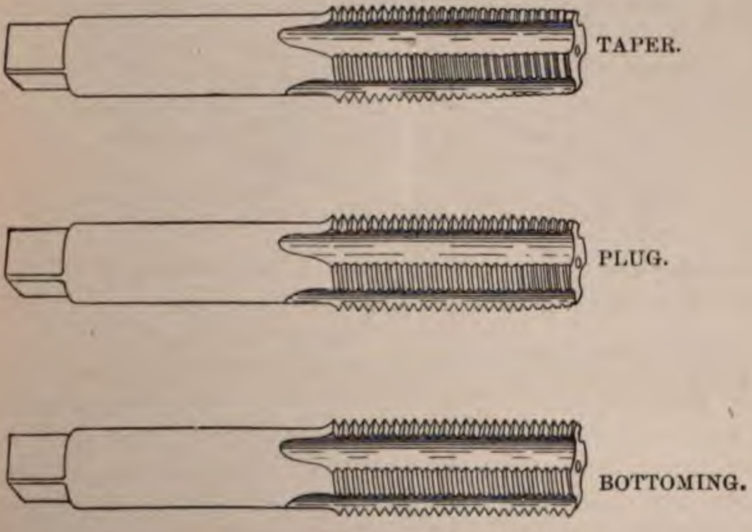


Fig. 80.

It is advisable to cut the tap slightly tapering, the thread being from .0005 to .001 inch smaller at the end toward the shank. This prevents the tap binding when slightly worn, yet it is not tapering enough to affect the accuracy of the thread. The thread tool should be an exact fit to the gauge, and placed in the tool post so that the top of the shank stands about level. The top of blade shown at A, Fig. 81, sh[illegible] ground parallel with the top of the shank; the cutting [illegible] the exact height of the point of the [illegible] makers consider it advisable to rough the thread nearly to size with a single point tool, finishing it with a chaser which may be held in the same holder. A chaser blade is shown in Fig. 82. After the thread is cut to size and the end chamferred, the tap is ready to be grooved in the milling machine. The tap is held between centers and the grooves cut with a cutter especially adapted to the size and style of tap. While the grooves should be cut with a milling machine cutter, it is possible to cut them in a planer or shaper, using a tool of the proper shape. Great care must be used not to stretch the tap by heavy chips, or by using a dull tool.

The grooves cut in taps are ordinarily termed flutes. When making taps for the market it is usual to cut four flutes in all taps up to and including 2½ inches diameter. But when taps are made in the shop where they are to be used, the number and shape of the grooves depend on the nature of the intended work. A tap that is to run through the work without any backing out, can have a different shaped flute from one that is to tap a deep hole in a piece of steel, where it is necessary to reverse the motion of the tap every two or three revolutions to break the chip, and also to allow the lubricant to reach the cutting lips.

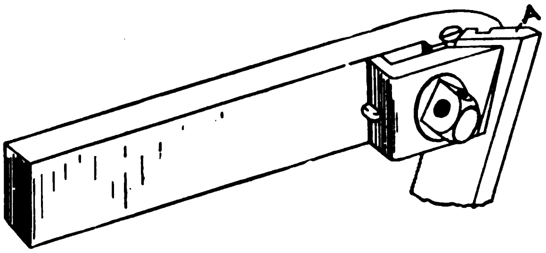


Fig. 81.

While all taps up to and 2½ inches diameter are usually given four straight flutes, spiral flutes are sometimes desirable, especially with small taps for some classes of work. With spiral flutes, it is generally necessary to cut a less number, and as taps are not ground after hardening, there is no objection to giving an odd number of teeth, as in case of a reamer. Three spiral flutes are often cut.

If a tap 1 inch in diameter, having four flutes of the regulation width, were used to tap tubing having thin walls, the tubing between the lands would have a tendency to close into the flutes of the tap, which might break the tubing. In such a case there should be double the number of flutes, in order to provide enough lands to hold the tubing in shape. If the hole to be tapped has part of its circumference cut away as shown in Fig. 83, more than four lands are necessary.

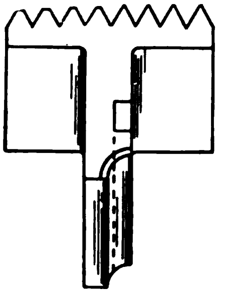


Fig. 82.

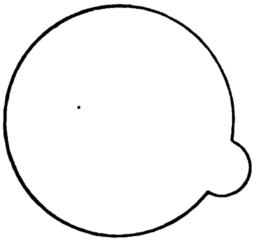


Fig. 83.

However, for general machine shop work four flutes work well in hand taps up to and including 2½ inches diameter. For larger sizes, some tool makers advocate six flutes ; others claim best results from taps having four flutes regardless of size. The class of work and the stock used in the individual shop must determine this.

Forms of Flutes. The most commonly used form of flute is that cut with a convex milling cutter (Fig. 84) for milling half circles. The advantages claimed for this form are: the flutes are of sufficient depth to provide for the chips, and yet leave the lands strong enough ; and the form of the back of the land is such that the chips cannot be wedged between the land and the work when the motion of the tap is reversed. The form of groove made with this cutter is shown in Fig. 85. In order to support the tap when starting to cut, and to prevent cutting the hole large at the outer end, hand taps have their lands left wider (as shown at A, Fig. 85) than is the case with machine taps. If the forms

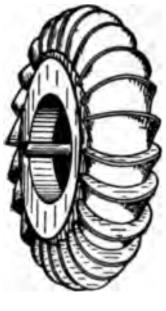


Fig. 84.

of cutter shown in Fig. 85 or Fig. 86 are used, the width of lands as shown at A may be one fourth the diameter of the tap. A Brown & Sharpe Tap and Reamer Cutter is shown in Fig. 86.

Fig. 87 shows a special form of cutter made by Brown and Sharpe. It does not make as deep a groove (Fig. 88) in proportion to the width as a Tap and Reamer Cutter.

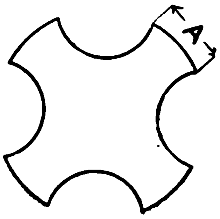


Fig. 85.

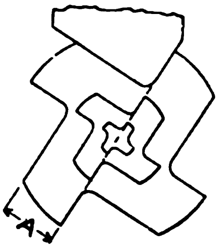


Fig. 86.

After cutting the grooves, the lands should be backed off to give the tap cutting edges; this is usually done with a file. Commence at the heel of the land, A Fig. 89, file the top of the land, and gradually approach the cutting edge, making sure that no stock is removed at that portion; simply bring it to a sharp edge. Enough should be filed off the heel A to make it cut readily, yet not enough to cause it to chatter. The size and number of threads per inch should be stamped on the shank of the tap. If it has a thread differing from that in general use in the shop, that should also be stamped on the shank, as U. S. S., if it is a United States Standard thread.

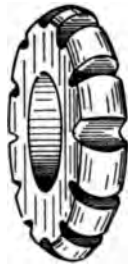


Fig. 87.

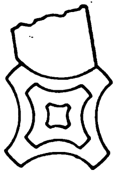


Fig. 88.

The following table gives the number of cutter for different diameters of taps when the form shown in Fig. 87 is used.

No.	1	Cutter	Cuts	Taps			to $\frac{1}{8}$	inch diameter.
"	2	"	"	"	from $\frac{5}{32}$	inches	" $\frac{1}{4}$	" "
"	3	"	"	"	" $\frac{9}{32}$	"	" $\frac{3}{8}$	" "
"	4	"	"	"	" $\frac{7}{16}$	"	" $\frac{5}{8}$	" "
"	5	"	"	"	" $\frac{11}{16}$	"	" $\frac{7}{8}$	" "
"	6	"	"	"	" $\frac{15}{16}$	"	" $1\frac{1}{4}$	" "
"	7	"	"	"	" $1\frac{5}{16}$	"	" $1\frac{5}{8}$	" "
"	8	"	"	"	" $1\frac{11}{16}$	"	" 2	" "

Hardening. If but a few taps are to be hardened at a time, it is customary to heat them in a gas jet or an open fire of charcoal or hard coal. It is advisable, however, to heat the taps gradually in a tube. They may be plunged one at a time into the bath a little above the threads. The tap should be worked up and down and around in the bath to prevent soft spots. Taps 1 inch diameter and smaller should be left in the bath until cold; if larger they may be removed from the bath as soon as the singing noise ceases, and immediately plunged in oil and left until cold. For taps less than ¼ inch diameter, the citric acid bath will be found satisfactory; for larger taps use strong brine.

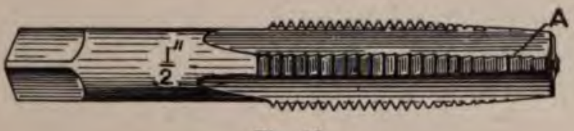


Fig. 89.

To have the tap retain as nearly as possible its size and correctness of pitch, use the "pack hardening" process. Run taps ⅛ inch diameter and smaller, ½ hour after they are red hot; taps ⅛ to ¼ inch diameter, 1 hour; taps ¼ to ½ inch diameter, 1¼ hours; taps larger than one inch diameter, 2 hours. Harden in a bath of raw linseed oil.

Fig. 90.

It is advisable to grind the flutes of the taps with an emery wheel of the proper shape in order to brighten the surface, so that the color may be readily seen when drawing the temper. It also sharpens the cutting edges and breaks the burrs that have been thrown between the teeth when cutting the flutes. The temper should be drawn to a full straw color. Much more satisfactory results may be obtained by heating the taps in a kettle of oil, drawing the temper to a point from 460° to 500°, according to the size of the tap and the nature of the stock to be cut.

MACHINE TAPS.

As the name implies, machine taps are intended for screw machines, tapping machines, and lathes. They are held in chucks or collets by their shanks, and are supported firmly. Consequently the lands may be made narrower than those of hand taps to make them offer less surface to the work, thereby reducing the amount of frictional resistance. Also, they may be relieved between the teeth, by filing with a sharp cornered three square file, commencing at the heel of the tooth and filing nearly to the cutting edge.

Fig. 91.

It is not good practice to relieve the teeth very much because chips may be drawn between the work and the lands when backing out of the work. When taps are to be used in an automatic tapping machine without reverse motion the shanks are left long as shown in Fig. 90 in order that the nuts may pass over the thread and on to the shank. When this is full the tap is taken from the machine and the nuts removed; this can be readily done as they will pass over the end of the shank.

If a tap is to be used on nuts whose holes are punched to size, much better results are obtained by using a tap having five flutes, as shown in Fig. 91, instead of four. The uneven number of cutting edges reduce the liability of an imperfectly tapped hole, while the extra land furnishes additional support.

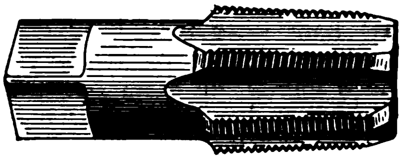
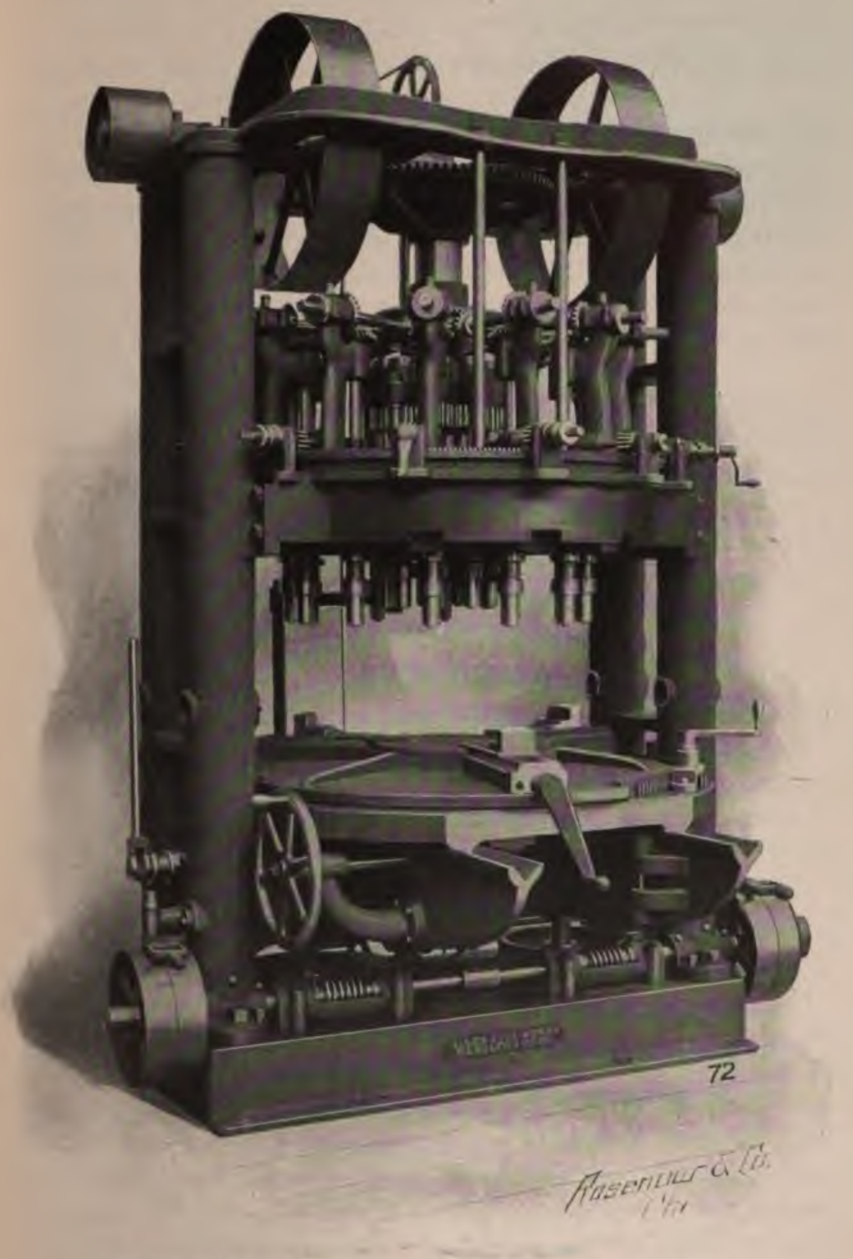


Fig. 92.

Taper Taps. When cutting the threads of a taper tap, Fig. 92, it is necessary to use a lathe having a taper attachment, as the pitch of the threads is not correct if the taper is obtained by setting over the tail stock. Like machine taps, the teeth of a taper must be relieved back of the cutting edge.

In setting the threading tool for cutting taper taps, care



TWENTY-SEVEN SPINDLE CAR-WHEEL DRILLING MACHINE.
Niles-Bement-Pond Co.

should be taken that it is square with the axis of the tap, rather than square with the taper sides.

Screw Die Hobs. Die hobs are finish taps for sizing the thread in screw cutting dies. The several flutes are narrower than those of an ordinary tap and the lands are correspondingly wider. The tap shown in Fig. 93 has eight flutes. The increased number and broader lands support the tap while running through dies whose clearance holes are drilled, in order to remove burrs thrown in the threads when drilling. It is customary to give screw die hobs six to ten flutes.

When hobs are used for solid dies they must be of exact size. When intended for tapping adjustable dies, such as are ordinarily used for cutting threads in screw machine work, the hobs are made from .003 to .005 inch above the size of the screw to be cut. The extra size gives relief to the threads of the die.

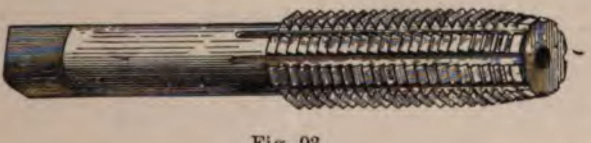


Fig. 93.

While it is generally considered advisable to run one or more taps through a die before the hob, some tool makers consider it better to make a hob that will do all the cutting, claiming that no two taps can be made and hardened so that the pitch will be exactly the same. In such cases a hob (Fig. 94) is made that will cut a full thread by passing through the die.

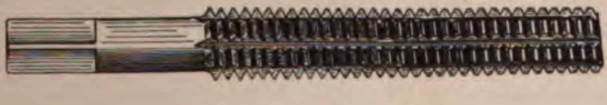


Fig. 94.

Some manufacturers cut the thread tapering for about three-quarters of the entire length of the thread, leaving the balance straight for use in sizing the die. Others cut the thread straight and taper the outside of the thread for three-quarters its entire length. If the threads are cut tapering, they must be relieved back of the cutting edges, as already described.

ADJUSTABLE TAPS.

A solid tap made to cut to exact size, having no leeway for wear, soon becomes too small. This is overcome by making a tap that may be adjusted from time to time. Another reason for making taps adjustable is that the holes may be tapped to fit hardened screws which vary in size on account of having been hardened.

Probably the most common form of adjustable tap is the one shown in Fig. 95. This tap is made in one piece, and then split. It has some means of adjustment whereby the tap may be expanded or contracted through a limited range. This may be accomplished by using a taper bodied screw. The hole to receive the screw should be drilled, tapped and taper reamed, before the tap is turned to size. The thread should then be cut and the taper thread cut on the end at A. There is less tendency to spring when the tap is hardened if the projection shown in Fig. 96 is provided; this may be ground off after the tap is hardened and tempered. After cutting the flutes, the tap may be split in the milling machine using a metal slitting saw; the tap should be held between centers. It is split on two opposite sides, as shown at B, Fig. 95. The splitting should not go to the end of the projection.

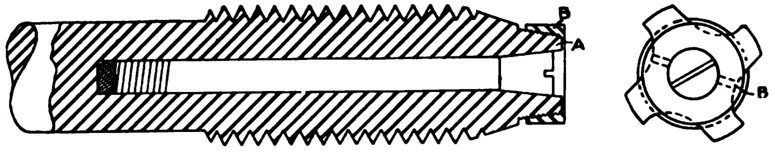


Fig. 95.

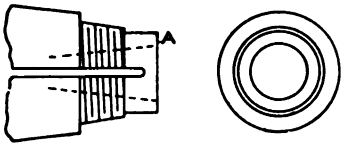


Fig. 96.

For hardening taps "Pack Hardening" is the best method. But, if it is impossible to use this method, heat the tap very carefully in a muffler furnace, or in a tube, having previously plugged the hole for the adjusting screw with fire-clay mixed with water to the consistency of dough. When the tap is heated to the proper degree it should be dipped in a bath of luke-warm brine, and worked up and down rapidly. After hardening, it should be ground in the flutes, and the temper drawn to a full straw color. The projection on the end may be ground off, the taper screw inserted, and the locking nut B, Fig. 95, screwed to place. This nut has a taper thread cut inside to correspond with the thread on the tap at A, Fig. 95. It will be found necessary to cut the taper thread on the tap and in the nut by means of the taper attachment.

Inserted Blade Taps. The first cost of an inserted blade tap may not be much less than that of a solid tap of the same size, yet on account of the comparatively small cost of new blades which can be inserted in the same body, or holder, when the first set becomes worn, this form is very valuable for taps larger than 1½ inches diameter. The tap shown in Fig. 97 may also be used as an adjustable tap. The shank or holder A is made of machinery steel, and the adjusting collars C C are beveled on the inside at one end at an angle corresponding to the angle on the ends of the blades. An angle of 45° will be found satisfactory.

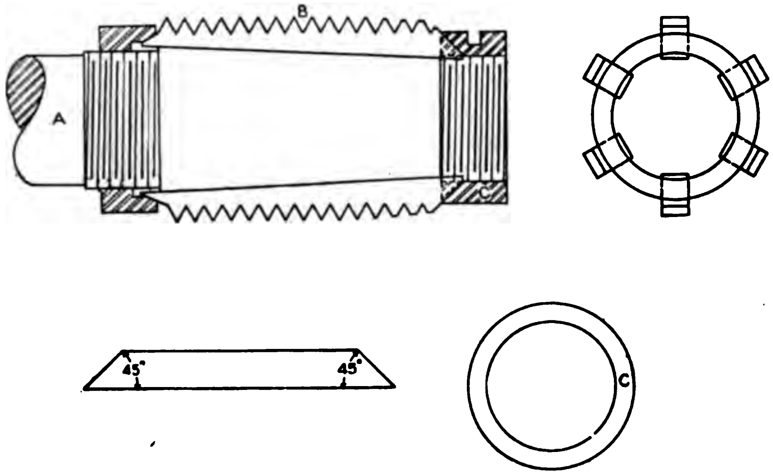


Fig. 97.

After turning the body, or holder to size, and cutting the threads to receive the nuts, the slots for the blades may be milled;

these should be cut deeper at the cutting end in order that any change in the location of the blades may alter the size of the tap. A taper of $\frac{1}{16}$ inch in three inches is ample. If the slots are milled on the universal milling machine, and the tap held in the universal centers the spiral head may be depressed sufficiently to give the desired angle. If a pair of centers of the form shown in Fig. 98 are used they may be held in the milling machine vise at the desired angle. The milling cutter should be set about $\frac{1}{32}$ inch ahead of the center in order that the face of the blade may be milled enough to take any inequality in the teeth at the cutting face of the blade occasioned by the thread tool striking the face when it starts to cut. The amount milled from the face should be just enough to leave the cutting face radial. The blades should be of an exact length and should fit accurately in the slots. A gauge of the form shown in Fig. 99 will insure uniform length. After the blades have been carefully fitted to the slots and to the gauge, they may be inserted in the holder and secured by the nuts as shown in Fig. 97. The outside diameter is then turned about

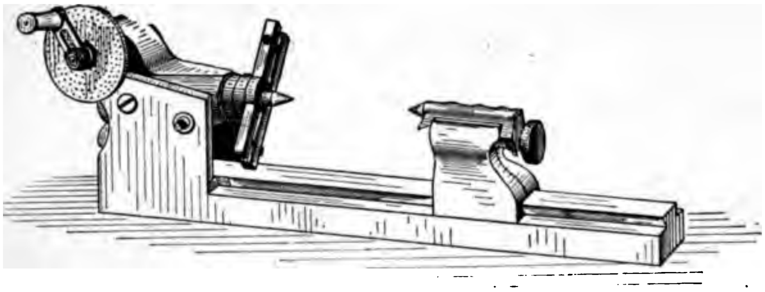


Fig. 98.

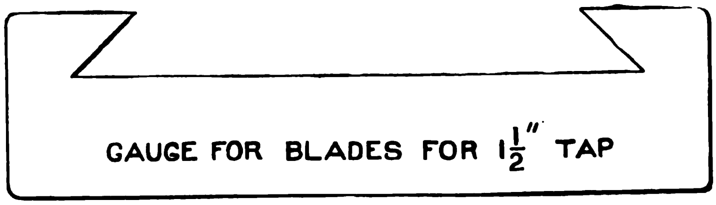


Fig. 99.

.005 inch smaller than the size the tap is to cut and the threads very carefully cut; after which the face of the blades may be milled as explained, the cutting end chamferred, and the necessary amount of clearance given the cutting edges by filing. The blades are now ready for hardening.

When hardening, the blades should be subjected to a slow heat in a muffler furnace, or a tube. When a blade reaches a low uniform red heat, it should be immersed in a bath of luke-warm water or brine, and worked up and down to insure uniform results. After hardening it may be brightened and drawn to a deep straw color. It is well to place all the blades in a pan having a long handle, as shown in Fig. 100. Coarse sand to a depth of about 1½ inches may be placed in the bottom of the pan with the blades. The pan should be placed over a bright fire and shaken carefully so that the teeth will not be dulled by striking the other hardened blades, while the sand and the blades are heating. The motion causes it to heat uniformly and the sand keeps the surface of the work bright so that the temper colors may be readily seen. This method of drawing temper will be found very satisfactory on many classes of work. It is also used extensively when coloring pieces by heat where a great many pieces are to be colored uniformly.

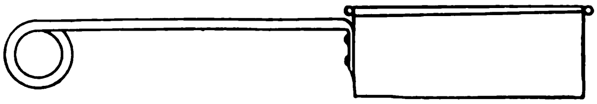


Fig. 100.

Square Thread Taps. Although the square thread is not as extensively used as formerly, having given place in many shops to the "Acme Standard," yet it is sometimes necessary to make taps for this form.

Steel should be selected sufficiently large and the decarbonized portion removed; the shank should be turned to size. The square should be milled for a wrench and the size and number of threads per inch stamped on the shank. The cutting end of the tap should be turned to size, the necessary amount of taper given the tap and then the threads cut

The tool used for cutting square threads is similar in form to a cutting-off (parting) tool except for its angle of side rake; it should be made of the proper thickness at the point but should be somewhat narrower back of the cutting end, as shown in Fig. 101, in order that it may clear when cutting.

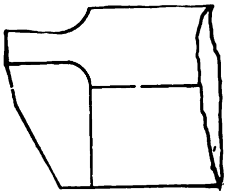


Fig. 101.

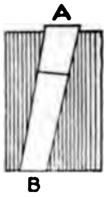


Fig. 102.

The thickness of the cutting end should be one half the distance from the edge of one thread to the corresponding edge of the next thread. For a square thread of 2 pitch, the land and space together would be ½ inch, while the land and space would each be ¼ inch wide. The point of the tool would be ¼ inch thick.

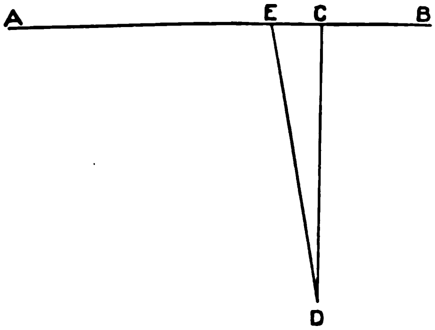


Fig. 103.

The sides of the tools from A to B, Fig. 102, must be inclined to the body as shown, the amount of the inclination depending upon the pitch of the thread and diameter of the tap to be cut. It may be determined, however, by the method shown in Fig. 103. Draw the line A B, and at right angles to it draw C D, whose length must be equal to the circumference of the thread to be cut, measured at the bottom or root of the thread. On A B lay off from the point C a distance E C equal to the pitch of the thread to be cut. Then draw the line D E, which will represent the angle of the side of the thread; the angle of the side of the cutting tool must be sufficiently greater to give the necessary clearance. It is advisable to cut the thread with a tool somewhat narrower than the required width at first, and finish with a tool of the proper thickness.

Square thread taps may be fluted according to directions given for V thread taps. If a tap is intended to cut a full thread, it must be well backed off, in order to avoid the necessity of using so much force that the tap would be broken. When a tap is to be used to size a hole whose thread has been cut by a smaller tap, very little clearance is necessary.

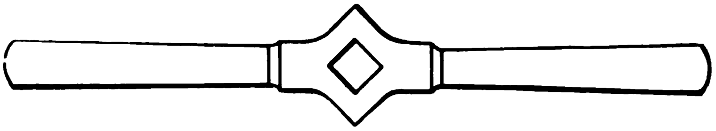


Fig. 104.

Tap Wrenches. When taps are used whose squares are all of a size, a solid tap wrench may be made, as shown in Fig. 104. This wrench is forged nearly to shape, the handles turned to size in the lathe, and the square hole in the center drilled and filed.

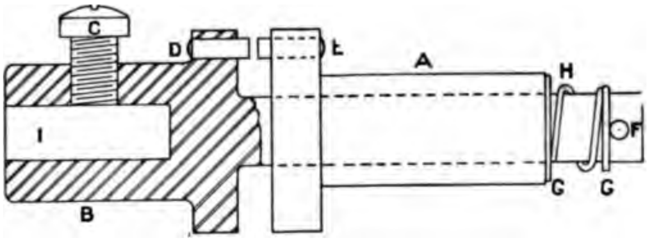
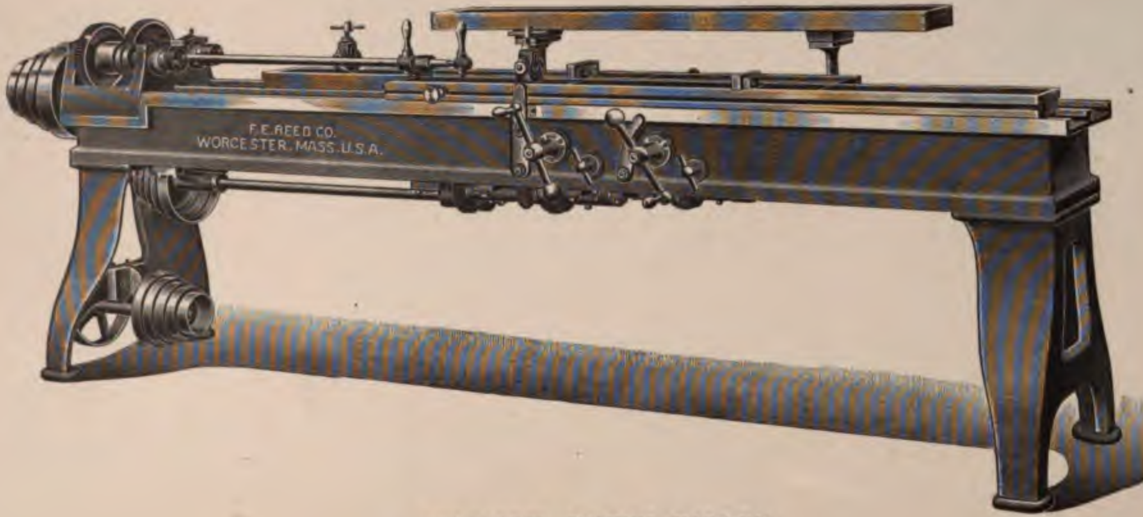


Fig. 105.

Releasing Tap Holders. When holes are to be tapped to a uniform depth in a screw machine or turret lathe, a tap holder is used which automatically releases the tap when it reaches the required depth. A very common form which gives excellent results when properly made and adjusted is shown in Fig. 105. It consists essentially of a sleeve A, which fits the tool holes in the turret of the screw machine, and the tap holder B, which fits the hole in the sleeve in such a manner as to slide longitudinally. The sleeve A should be made of tool steel if of a diameter that makes the wall around the hole thin; the hole should be drilled and reamed to size, and the outside turned to size. The portion of the sleeve which enters the hole in the turret should be a snug fit. The tap holder B should be made of tool steel, or of a grade of machinery steel possessing great stiffness and good wearing qualities. After roughing out to sizes somewhat larger than finish, the end which is to hold the tap may be turned to size and the (stem) end which is to run in the sleeve may be fitted, after which the hole I, to receive the tap may be made of a convenient size. In order that the hole may be perfectly concentric with the holder it will be necessary to run the large end of the holder in the steady rest of the lathe; the opposite end should be fastened against the head center of the lathe in such a manner that the stem runs perfectly true. With work of this nature, the head center of the lathe must be in good condition and run true.

After the hole has been drilled somewhat smaller than finish size, it is necessary to true the hole with a boring tool; the hole should be bored to within .010 inch of finish size, after which it may be reamed with a rose reamer. Before reaming, however, the outside edge of the hole should be chamferred to the shape of the point or cutting end of reamer, to avoid any possibility of the reamer running. Some tool makers never ream a hole of this nature if it can be avoided, always boring to size with a tool that makes a smooth cut; but if extreme care is used, results good enough for a tool of this character may be obtained if the holes are finished to size with a reamer.


F. E. REED CO.
WORCESTER, MASS. U.S.A.

GUN-BARREL REAMING MACHINE.
F. E. Reed Company.

TOOL MAKING.

PART II.

THREAD CUTTING DIES.

The size of a die is always denoted by the diameter of screw it will cut; a die that will cut a ½ inch screw is called a ½ inch die, irrespective of the outside diameter of the die itself.

Thread cutting dies are made solid or adjustable. Solid dies are used when extreme accuracy is not required. They are comparatively inexpensive, and may be used to advantage as a roughing die when an adjustable die is used for finishing. Owing to the tendency of dies to change their sizes when hardened, and to the fact that there is no provision for wear, they cannot be used where work must be made to gauge. They are extensively used in cutting threads on bolts, and for this class of work are made square, as shown in Fig. 106.

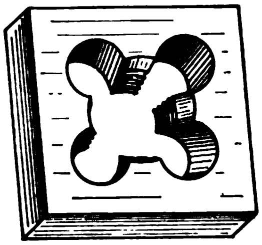


Fig. 106.

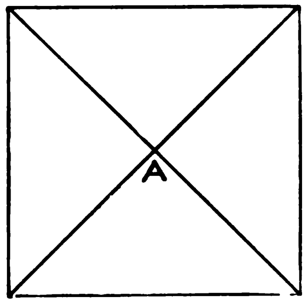


Fig. 107.

In making a square die the blank may be machined to thickness and to size on the square edges. One of the flat surfaces should be coated with blue vitriol, or the blank may be heated until it shows a distinct brown or blue color. The center may be found by scribing lines across corners, as shown in Fig. 107. It should be prick punched at A where the lines intersect. The die blank may be clamped to the face plate of a lathe and made to run true by means of the center indicator. If there is no tap of the proper size, and only one die is to be made, the thread may be cut with an inside threading tool, provided the hole is of sufficient size; if not, a tap must be made. If the thread is cut with a threading tool, the size must be determined by means of a male gauge, which may be a screw of the proper size. After threading, the hole should be chamferred to a depth of three to four threads, the amount depending on the pitch of the thread; a fine pitch not requiring as many threads chamferred as a coarse pitch. The chamferring should not be much larger on the face of the die than the diameter of the screw to be cut. Figs. 108 and 109 show two views of a die chamferred and relieved on the cutting edges. The chamferring may be done with a countersink or taper reamer of the proper angle. In the absence of such a cutter, a tool held in the tool post of the lathe may be used.

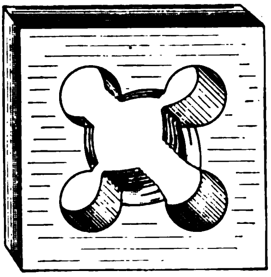


Fig. 108.

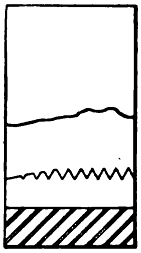


Fig. 109.

Most manufacturers making dies for the market give four cutting edges to all sizes up to and including four inches. When dies are made in the shop where they are to be used, custom varies. Some tool makers advocate three cutting edges for all dies smaller than $\frac{1}{4}$ inch, and five or more cutting edges for dies above two inches. The objection to more cutting edges than are absolutely needed on large dies is the increase in the cost of making.

When making dies for threading tubing, or for work where part of the circumference is cut away, it is better to give them a greater number of cutting edges than would otherwise be the case.

Rake of Cutting Edges. For general shop work, where the dies are t of stock, it is advisable to make

Fig. 110, the cutting edges

A A A A all pointing to the center. For cutting brass castings, the cutting edges should have a slight negative rake as shown in Fig. 111, the cutting edges A A A A all pointing back of the center.

Clearance Holes. After threading and countersinking (chamferring), screw in a piece of steel threaded to fit the die, and face it off flush. Lay out the centers of the clearance holes on the back of the die, and drill with a small drill the size of the pilot of a counterbore whose body will cut the right size for the clearance hole. The centers of these holes for dies having four cutting edges, and from $\frac{3}{8}$ to $\frac{3}{4}$ inch may be the intersections of a circle having a diameter equal to the diameter of the screw to be cut, and lines drawn across the corners as shown in Fig. 112. Prick punch these points. For a die having four clearance holes whose centers are laid out as shown in Fig. 112, it is customary to make the clearance holes one half the size of the die; that is the size of clearance holes in a $\frac{1}{2}$ inch die would be $\frac{1}{4}$ inch. The width A, Fig. 113, of the top of the lands should be about $\frac{1}{16}$ of the circumference of the screw to be cut. The diameter of clearance holes given does not apply to dies smaller or larger than sizes given ($\frac{3}{8}$ to $\frac{3}{4}$ inch), especially if the dies are to be used in the screw machine, as the clearance hole not only

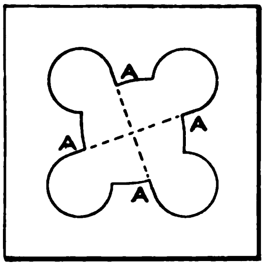


Fig. 110.

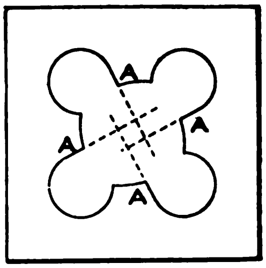


Fig. 111.

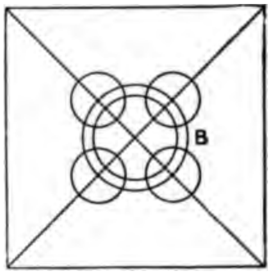


Fig. 112.

provides a cutting edge, but also makes a convenient place for the chips; if these are so small that the oil cannot wash the chips out, the chips clog the holes and tear the thread.

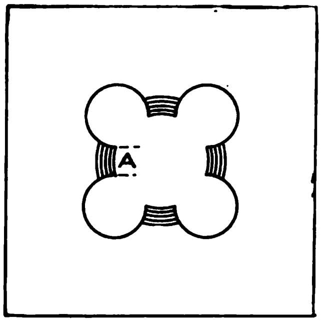


Fig. 113.

For small dies the clearance holes are of a size that allows the chips to collect in the holes without tearing the threads, and are located a greater distance from the center of the die, in order to give sufficient strength to the lands. The desired shape and thickness may be given the sides of the lands by filing. When it is considered advisable to give screw dies above $\frac{3}{4}$ inch larger clearance holes than the size mentioned, they may be located at a distance from the center of the die that will give the desired thickness to the land.

For screw machine and turret lathe work, dies are generally made circular, and as holders for dies are part of the equipment of every shop having screw machines, the dies should be made to fit these holders; but it is not considered good practice to make the diameter of dies less than $2\frac{1}{2}$ times the diameter of the screw to be cut, and the thickness of the die may be $1\frac{1}{4}$ times the diameter of the screw.

ADJUSTABLE DIES.

While round dies for screw machine work may be made solid for roughing out a thread that is to be finished by another die, the finish die should be made adjustable in order that the desired size may be obtained. When making adjustable dies the same general instructions may be followed that are given for making solid dies, except that some provision must be made for adjustment. This is done by splitting the dies at one side as shown at A in Fig. 114. In order that the die may not spring out of shape in hardening, it is advisable to cut the slot from the center of the die, leaving a thin margin as shown at A, Fig. 115; after the die is hardened this may be cut away with a beveled emery wheel. If the thickness at B is too great to allow the die to close readily when adjusted to size, the hole shown may be drilled and connected with the clearance hole by means of a saw cut.

If many round dies of the same diameter are to be made it is economical to have a holder with a shank which fits the hole in the spindle of the lathe; the opposite end should be made to receive the die blanks which should be turned to fit the die holder in the screw machine. Fig. 116 shows the holder to be used in the lathe. A represents a die blank in the holder; B is the shank which fits in the spindle of the lathe; C is a recess in the holder to provide for the projection left on the blank when it is cut from the bar and also provide an opening to receive the drill and tap after they run through the die. After the blank is placed in the holder and secured in position by the screw D, the outer surface may be faced smooth and true with the circumference, after which it may be reversed and the opposite side finished to the proper thickness. The die may now be drilled and tapped. Be-

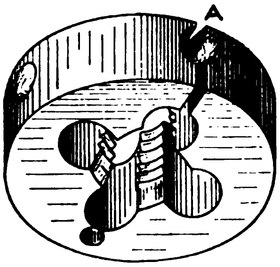


Fig. 114.

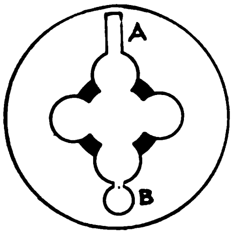


Fig. 115.

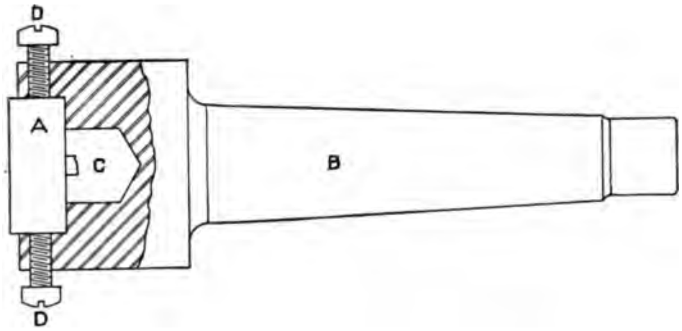


Fig. 116.

fore drilling, the die should be carefully centered in the lathe; to insure a full thread in the die, a drill a few thousandths of an inch smaller than tap size should be used in drilling, after which a reamer of the proper size may be run through. When tapping the thread, it is advisable to use two or three taps of different sizes; the finish tap should be the size of the desired hole in the die, and should be of the form known as screw die hob. Where several taps are used in tapping a die, there should be some difference in the diameter so that any inequality in the shape or pitch of the thread may be removed by the larger tap, otherwise imperfect threads will result. For instance if three taps are to be used for a ¼ inch die, the first tap may be .230 inch diameter; the second .240 inch diameter, and the finish tap .250 inch diameter if the die is to be solid. If it is to be an adjustable die, the finish tap should be .253 inch diameter in order to furnish clearance to the lands when it is closed to .250 inch.

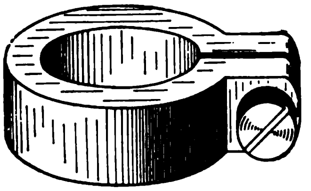


Fig. 117.

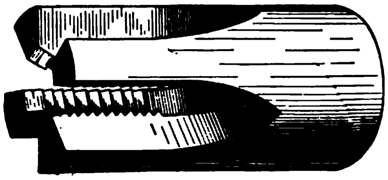
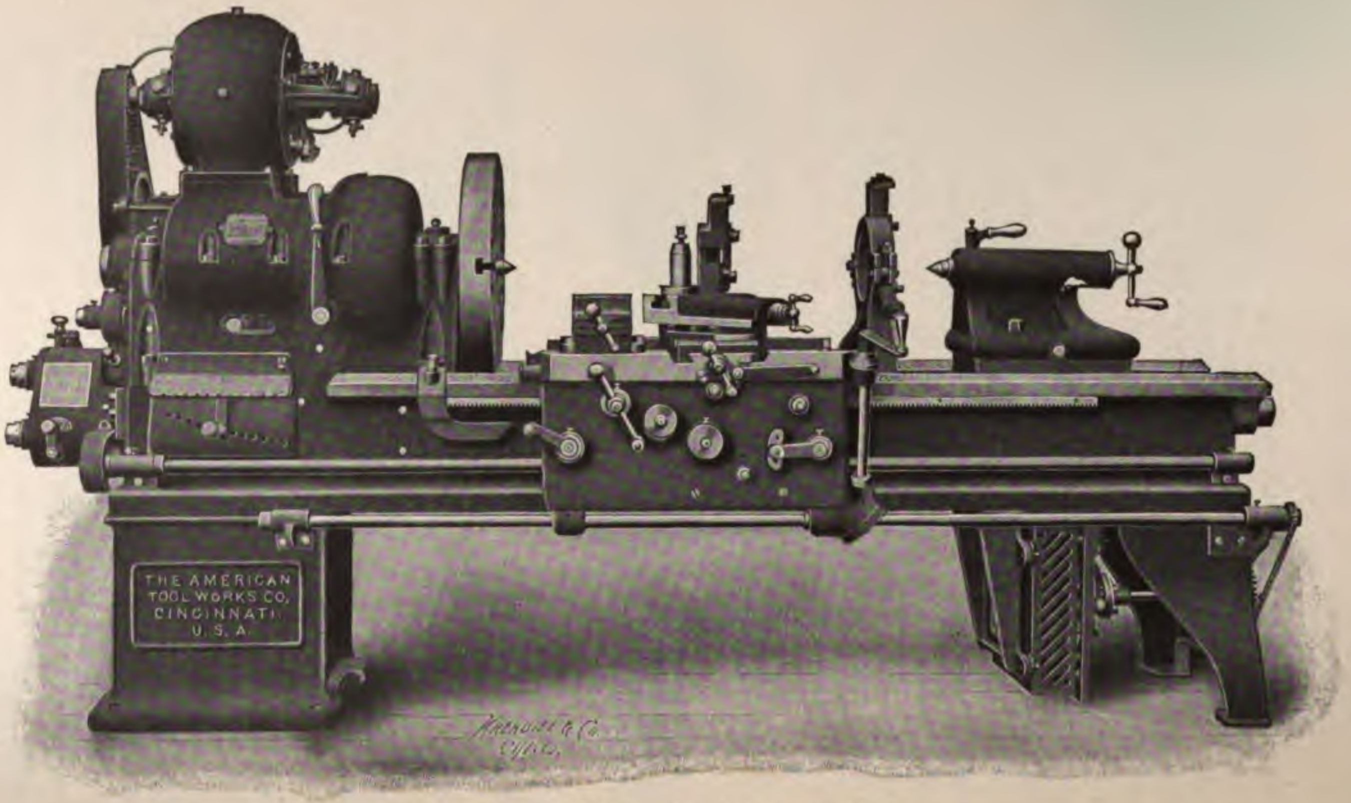


Fig. 118.

Dies should be heated very slowly for hardening, either in a muffler furnace, or in some receptacle to protect it from the action of the fire. When the die is heated to a uniform low red it may be immersed in a bath of lukewarm brine and worked back and forth to insure hardening the threads. The temper should be drawn to a full straw color. If it is an adjustable die the portion marked B, Fig. 115, should be drawn to a blue color in order that it may spring without breaking; this may be done by placing this portion of the die on a red hot iron plate, or the jaws of a heavy pair of tongs may be heated red hot, the die may be grasped in the tongs and held until the desired color appears. Do not allow the blue color to extend to the threads or they will be too soft. When the desired color has been obtained the die may be dropped into oil to prevent drawing the temper more than is desired.



MOTOR-DRIVEN AMERICAN ENGINE LATHE.

Spring Screw-threading Dies. This form of die is adjusted by means of the clamp collar shown in Fig. 117; the die is shown in Fig. 118. In some shops it is the only form of screw-threading die used for screw machine work. When so used it should be fitted to one of the holders on hand, provided there be one of the proper size.

Average proportions of spring dies are given in the following table; these sizes are used by a manufacturing concern using a great many screw-threading dies of this description. It is not necessary to follow the proportions given, as they are intended only as a guide, and may be changed to suit circumstances. All dimensions are in inches.

SPRING SCREW-THREADING DIES.

Size of Screw.	Outside Diameter.	Length.
$\frac{1}{8}$ to $\frac{1}{4}$	$\frac{1}{2}$	$1\frac{1}{4}$
$\frac{1}{4}$ to $\frac{3}{8}$	$\frac{3}{4}$	$1\frac{3}{4}$
$\frac{3}{8}$ to $\frac{1}{2}$	1	2
$\frac{1}{2}$ to $\frac{3}{4}$	$1\frac{1}{4}$	$2\frac{1}{4}$
$\frac{3}{4}$ to 1	$1\frac{5}{8}$	$2\frac{1}{2}$
1 to $1\frac{1}{4}$	2	3
$1\frac{1}{4}$ to $1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$
$1\frac{1}{2}$ to 2	$3\frac{1}{4}$	4

For uniform and well-finished threads, two dies should be used, one for roughing, and one for finishing.

Where many dies of a size are made it is best to have a holder with a shank fitting the center hole of some lathe. The stock can be machined to size and cut to length. The clearance hole in the back of the die should be first drilled somewhat larger than the diameter of the screw to be cut. For dies up to and including $\frac{1}{8}$ inch the clearance holes should be $\frac{1}{32}$ inch large; for dies $\frac{1}{8}$ to $\frac{1}{4}$ inch it should be $\frac{3}{64}$ inch large; for dies $\frac{1}{2}$ inch and over, it should be from $\frac{1}{16}$ to $\frac{1}{8}$ inch large. After drilling the clearance hole, the die should be reversed in the holder, and drilled and tapped the same as a round die, using a hob to finish the threads to size. For general work, the die should have four cutting edges making the lands about one-sixteenth the circumference of the screw to be cut. Chamfer about three threads. The length of the threaded portion of the die should not exceed one and one-quarter times the diameter of the screw to be cut. To produce the cutting edges, use a 45° double angle milling cutter shown in Fig. 119; this cutter should be of sufficiently large diameter to produce a cut as shown in Fig. 120.

The chamferred edges should be relieved and the cutting edges finished with a fine file. Stamp the size and number of threads on the back end of the die as shown in Fig. 120 and then harden. The die should be heated in a tube and hardened in a jet of water coming up from the bottom of a tank in order that the water may enter the threaded portion. It should be hardened a little farther up than the length of the thread, moving up and down in the bath to prevent a water line; the temper should be drawn to a full straw color.

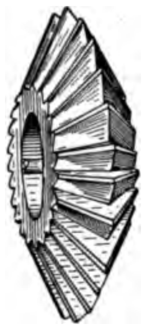


Fig. 119.

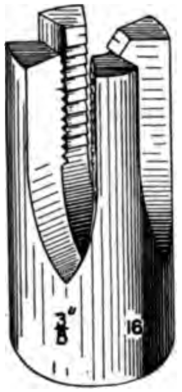


Fig. 120.

Where many clamp collars are used, castings of malleable iron or gun metal may be made from a pattern; the hole should be cored to within $\frac{1}{16}$ inch of finish size. The hole may then be drilled and reamed. When the screw hole has been drilled and tapped and the collar split, it is ready to use. If the surfaces are finished it adds very materially to the cost.

Die Holders. When cutting threads in screw machines and turret lathes, dies are held in die holders which are constructed in two parts as shown in Fig. 121. The shank A fits the hole in the turret, while the die holder B has a stem that fits the hole in the shank. While the die is cutting, the pins D and C are engaged, thus preventing the holder B from turning. When the turret slide of the screw machine has traveled to its limit, the holder is drawn out of the shank until the machine is reversed when the pins engage on their opposite sides. A pin is put through the stem of the holder at E; this strikes the end of shank just at the time the pins D and C become disengaged.

Both shank and body may be made of machinery steel; the shank may be finished to size except the portion marked A, which should be left .010 inch large for grinding. The front end of the hole should be rounded as shown in Fig. 121, to allow the fillet in the shoulder of the stem to enter. This fillet is left for strength. The pin hole should be drilled and reamed. When the holders are to take dies not over $\frac{1}{8}$ inch in size, this pin hole may be $\frac{3}{16}$ inch diameter; from $\frac{1}{8}$ to $\frac{5}{16}$ in size, $\frac{1}{4}$ inch diameter. As the dies increase in size the pin must increase proportionately. The shank may be case-hardened in a mixture of granulated charred leather and charcoal; it should run about two hours and then be dipped in a bath of oil. The hole should be lapped straight and true. The outside ground to fit the hole in the turret. The pin C should be of tool steel hardened and drawn to a blue color, and forced into place.

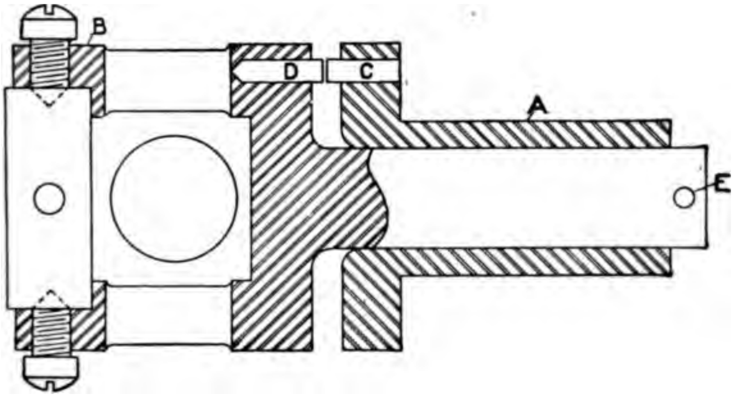


Fig. 121.

The holder B may be made from a forging, or turned from a solid piece. After roughing to size somewhat larger than finish, the stem may be turned and fitted to the hole in the shank; it should turn *freely* in the shank. The larger portion (or body) uld now be turned to size. This should be run in the steady ; and the end drilled and bored for the die and for clearance back of the die as shown in Fig. 121. Three or four large holes should be drilled into the clearance hole in order that the chips and oil may find a way of escape, thus preventing injury to the threads of a screw long enough to reach through the die when being threaded.

Screw holes should be drilled and tapped as shown in Fig. 121; the screws are to hold the die in position in the holder and also to adjust to size dies that are split. The stem may be placed in the shank and the pin hole transferred through the pin hole in the shank into the body; this should be done before the pin C is pressed into place. The pin D should be hardened the same as C.

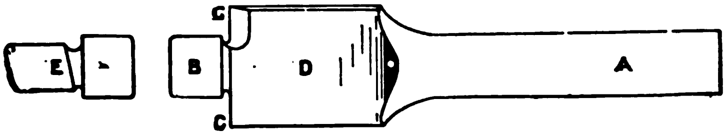


Fig. 122.

The pin hole for the pin E may be drilled in a location that allows C and D to become disengaged and yet have no play between the two

COUNTERBORES.

Counterbores are used for enlarging a hole without changing its relative position. For a *hurry up* job and for a small number of holes, it is advisable to make as cheap a form as is consistent with the work to be done. Probably the cheapest counterbore that will do satisfactory work is the flat form shown in Fig. 122. This can be forged to require but little machine work. After forging, turn to size; finish the shank A and pilot B with a fine file before taking from the lathe. The cutting edges C C should be faced true and smooth. The necking between the pilot and the body should be cut with a tool having the corners slightly rounded to decrease the liability of cracking when the counterbore is hardened. The flat sides D of the body may be finish filed; the edges should be draw-filed, removing more stock on the back than on the cutting edge to prevent binding. File the cutting edges C C for clearance, as shown at E, Fig. 122. The pilot and the body should be hard the entire length or they will wear and rough up and consequently cannot cut a smooth hole; draw the temper to a full straw color. Unless intended for *accurate* work it need not be ground.

For permanent equipment, counterbores are usually made with four cutting edges as shown in Fig. 123 and Fig. 124. Fig. 123 representing a taper shank counterbore for a taper collect, while Fig. 124 has a straight shank to be used in a chuck, or collet having a straight hole the size of the shank.

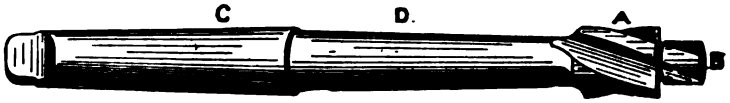


Fig. 123.

Counterbores for screw holes are usually made in sets of three, one for the head of the screw with pilot (or guide) of body size, one for head with pilot of tap drill size, and one to enlarge a tap drill hole to body size. The following instructions apply to counterbores with either straight or taper shanks. Take stock somewhat larger than finish size of counterbore.

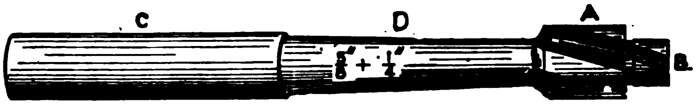


Fig. 124.

Turn a roughing chip all over the piece; turn the necked portion between the shank and body to size and stamp size of counterbore and pilot as shown in Fig. 124; turn shank C, body A, and pilot B .015 to .020 inch above finish sizes, to allow for grinding. In the case of the taper shank counterbore shown in Fig. 123 the tennon should be milled. The counterbore is now ready to have the grooves milled to form the cutting edges. One method is to cut them with a right-hand spiral of from 10° to 15°; the other method is to cut the grooves straight. The former has he effect of running chips back from the cutting edges and works very well on wrought iron and steel, while the latter method is considered more satisfactory for brass and cast iron and also works well on wrought iron and steel. The cutting edges are given clearance by filing, as shown at A in Fig. 125. If the counterbore is to be used for brass it is necessary to give clearance to the lands also as shown at A A A A, Fig. 126.

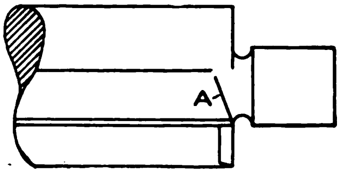


Fig. 125.

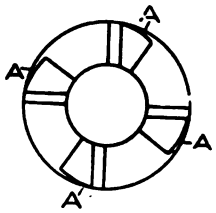


Fig. 126.

When centering counterbores or any tools whose centers are not to be used after the tool is finished, the drill should be small and the countersinking no larger than is necessary for good results in machining. If large centers should, by accident, be put in the ends, the one on the end to be hardened should be filled with fire clay moistened with water to the consistency of dough, or with graphite mixed with oil; this prevents steam forming in the hole and cracking the tool when dipped in the bath. If the piece is to be heated in lead, the filling should be dried thoroughly before immersing in the red-hot lead.

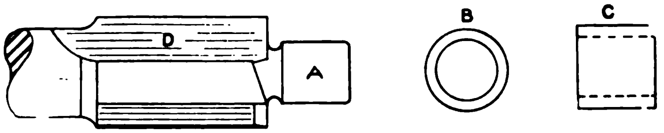


Fig. 127.

Solid counterbores can be used with holes larger than the pilot by forcing a sleeve over it as shown in Fig. 127. B and C are two views of the sleeve which is to be forced on to pilot A. After hardening, the counterbore may be ground to size on the shank, body and pilot; the shank should be ground first as the length is greater, and in the case of a counterbore having a straight shank the grinder may be adjusted to perfect alignment by measurement.

Two lipped counterbores are sharpened by grinding on the flat faces marked D, Fig. 122. Grind a four-lipped counterbore on the flat side of the groove as D in Fig. 127.

Facing Tool with Inserted Cutter. Where a limited number of holes are to be counterbored, the tool shown in Fig. 128 may be made. All that is necessary in making this tool is a piece of stock A, the size of the hole to be counterbored and a piece of drill rod for the cutter B; this may be filed to a cutting edge, hardened and driven in place. If accuracy is essential, a piece of drill rod must be cut off somewhat longer than the diameter of the required hole; it should be driven into the hole in the bar leaving an equal length on each side. It may be turned to the correct diameter and filed to shape. If several cutters are to be used in the same bar, or if the tool is to be used as a facing bar, to square a shoulder inside a piece of work as shown in Fig. 129, the cutter B is removed from the bar and after the bar is in place it is inserted and held by set screw C.

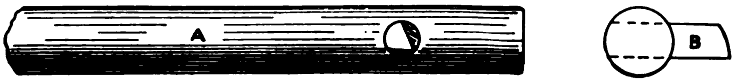


Fig. 128.

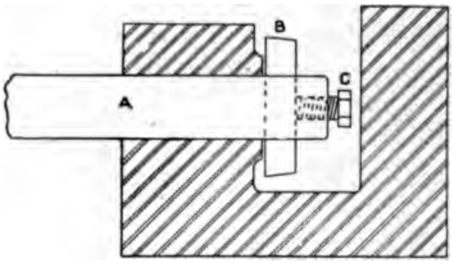


Fig. 129.

For large work, a counterbore may be made as shown in Fig. 130, A being the cutter bar which should be made of tool steel $\frac{1}{16}$ to $\frac{1}{8}$ inch larger than finish size. After taking a roughing chip, leaving it a trifle large, the slot should be made to receive the cutter C. This is done by drilling a series of holes as shown in Fig. 131. After prick punching the bar, it should be clamped to a drill press table, holding the bar in a pair of V blocks. The prick punch marks should be set in a position that will insure the drill holes going through the center of the bar; this can be done as follows: place the square against one side of the bar, measure to the center, then place the square against the opposite side and measure in the same manner. When the distance is the same on each side from the square blade to the centers, the piece is in the proper position for drilling. The drill press table may then be swung around until the prick punch marks are in proper location with the spindle of the press. After drilling, a drift may be driven through to break the walls separating the holes and the slot filed to size. The bar should be placed with one end in the steady rest and the other end strapped to the head center of the lathe. The screw hole in the end is now drilled and tapped into the slot in order that the screw may bind the cutter. The end should be countersunk to provide a center for fin'sh turning. The bar may be turned to size at A and the pilot finished to size. The screw D should have a head $\frac{1}{16}$ inch larger than the part B in order that it may hold the sleeve in place, should it have a tendency to come off when removing the counterbore from the hole. The cutter C should be a close fit in the slot. A headless screw sho [illegible] will not interfere with the d [illegible] ed to place against the

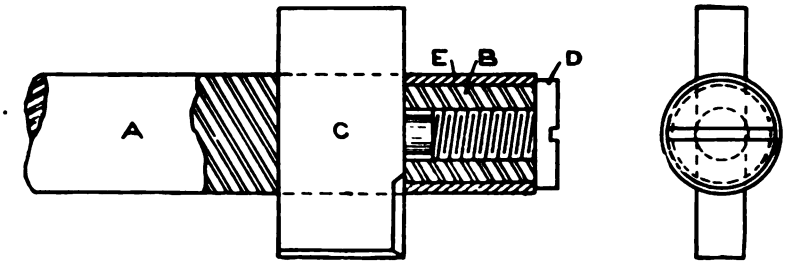


Fig. 130.

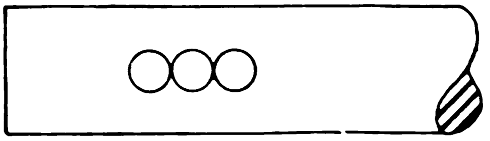
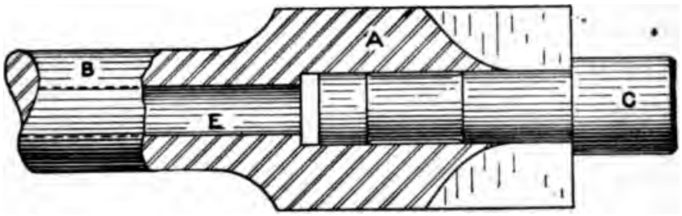


Fig. 131.

cutter blank. It is intended to be used when turning the cutter to the right diameter, and should be kept for that purpose.

Counterbores with Inserted Pilots are useful when the counterbores need frequent sharpening, or when a variety of different sized holes are to be counterbored to the same size. A common form of counterbore having an inserted pilot is shown in Fig. 132.



Fig, 132.

When making this counterbore the stock should have a roughing chip taken off and the hole E drilled part way from the shank end. This drilling may be done in the speed lathe, holding the drill in a chuck in the head spindle; the center in the opposite end of the piece should be on the dead center of the lathe. If the piece is turned one-half revolution occasionally the drill will cut accurately enough, as perfect alignment is not necessary in this hole, since it is intended only for use when driving out the pilot.

After drilling, the shank end should be carefully countersunk. The piece may now be turned to grinding size which should be from .015 to .020 inch all over. After turning the outside, the hole for the pilot may be drilled and bored, running the large end of the counterbore in the steady rest. The counterbore should have four cutting edges for all ordinary work; these may be cut with a side milling cutter with a face sufficiently wide to cover the width of tooth. The form of cutter is shown in Fig. 133, while an end view of the teeth is shown in Fig. 134. When mil-

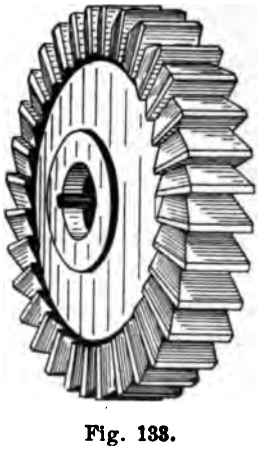


Fig. 133.

ling the teeth, the counterbore can best be held in the chuck on the spiral head. If a more stubbed form of tooth is needed than the one shown in Fig. 132, the spiral head may be tipped to the desired angle and the cutter fed through instead of sunk into the counterbore. After milling, the burrs should be removed, the counterbore stamped and hardened. While hardening, it should be heated to a red nearly the whole length of body; when dipped in the bath it should be inverted in order that the teeth may be uppermost, it should then be worked up and down rapidly in the bath until the red has entirely disappeared. It should be allowed to remain in the bath until cold. If larger than 1 inch diameter the *strain* should be removed immediately upon taking from the bath by heating over the fire as already explained. The pilot should be turned as shown in Fig. 135. A and BB should be left

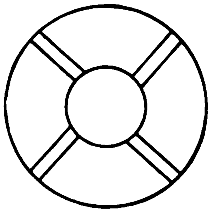


Fig. 134.

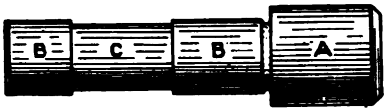


Fig. 135.

about .010 inch large for grinding after hardening; C should be turned $\frac{1}{32}$ inch smaller than the hole in the mill, as this does not bear when the pilot is in place. A slight depression should be made between the head and the first bearing point B for the emery wheel to pass over when grinding. When hardening, A is the only part that needs to be hard, but, unless a piece of tube is slipped over the stem B when the pilot is put in the bath it will be almost impossible to harden A the entire length and leave B soft. As A is likely to rough up when used it is best to harden a short distance on the stem B, unless there should be a great difference in size between A and B; in which case a tube, or a piece of iron with a hole drilled in the end the size of B and having the end beveled as shown in Fig. 136, should be slipped over B when the pilot is heated. This cover should be slipped over the stem and up against the shoulder of the head to prevent a *water line*;

if this precaution is taken there is no danger of pilot cracking under the head. After hardening and tempering, the pilot may be ground to size at A, and the portions B B ground to fit the hole of the counterbore. After grinding, the pilot may be forced into place. The counterbore may be ground with the pilot in position. When dull the pilot should be forced out of the counterbore and the cutting edges ground with an emery wheel.

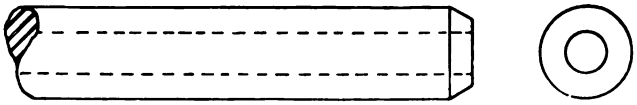


Fig. 136.

Combination Counterbores are made when it is necessary to change the size of counterbore and pilot frequently. A shank or bar is made to accommodate different sizes of cutters, and sleeves serve as pilots. In Fig. 137, A is the cutter, B the pilot which is tapped in the end to receive a screw which holds the sleeves, and C the shank which is held in a chuck or collet, when the counterbore is in use.

After taking a roughing chip off the bar, the end B is run in the steady rest and the hole for the screw F is drilled and tapped. The outside end is countersunk to a 60° angle to run on a center. When machining the holder, the portions B, C, and D should be left about .010 inch larger than finish size to allow for grinding. But if no grinder is at hand it may be left a few thousandths of an inch above size, and filed to finish dimensions.

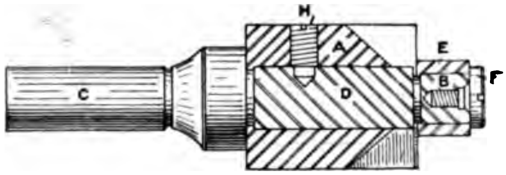


Fig. 137.

The body (or cutter) A, should have a hole $\frac{1}{16}$ inch smaller than finish size drilled through it; the outside surface should be turned off, and the piece annealed. If a grinder having an internal grinding attachment is at hand, the hole in the cutter should be left .005 inch small for grinding. If such an attachment is not at hand the hole may be reamed to finish size. The outside diameter should be left about .010 large; the ends should be faced to length, and the teeth cut. If four teeth are to be cut, the work may be done with a side milling cutter as shown in Fig. 133. The counterbore should be held in a chuck on the spiral head spindle, which should be tipped to produce a strong tooth as shown in Fig. 137. Before hardening, the hole should be drilled and tapped for the screw H which holds the counterbore to the bar. To harden, the counterbore should be given an even, low red heat, and plunged in water or brine in such a manner that the bath will come in contact with the teeth. If the teeth are stubbed and strong the temper need not be drawn more than to a ligh straw color.

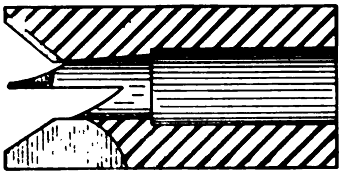


Fig. 138.

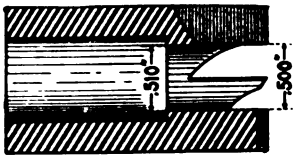


Fig. 140.

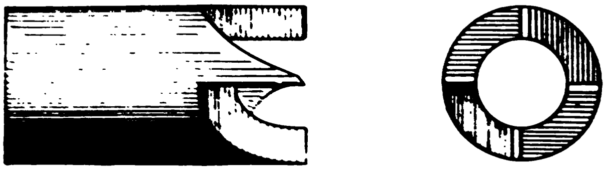


Fig. 139.

The screw H should be made of tool steel having a proje tion [illegible] inch long on one end, turned to the bottom of the threa this is to enter a hole drilled in the bar or holder, and keep t counterbore from turning. The end of the screw should be ab .005 inch smaller than the hole. The screw should be harde and drawn to a bl [illegible] color. The sleeve intended to go on pilot [illegible] hardened and ground to a [illegible] made of machinery and case-hardened sufficiently deep by heating to a red and sprinkling with powdered cyanide of potassium, after which it is reheated and plunged in water.

HOLLOW MILLS.

Hollow mills are used in screw machines and turret lathes for roughing down and finishing. They are also used in drill press work in finishing a projection which must be in some given position; when thus used they are generally guided by a bushing in a fixture, to bring the projection in the proper location.

For roughing out work on a screw machine or turret lathe, solid mills having strong stubbed teeth are preferred for rigidity. For finishing they are made adjustable in order to get *exact* sizes. Fig. 138 shows a solid hollow mill having the cutting end hollowed out in the form of a V, in order that it may center itself when starting to cut. Fig. 139 shows a form of solid hollow mill intended for use in squaring up a shoulder at the end of a cut that has been made with a mill of the form shown in Fig. 138, or it may be used for roughing out a piece; however, it will not center itself as readily as the one shown in Fig. 138.

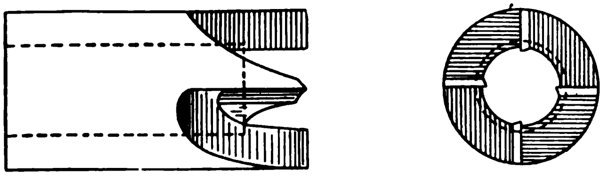


Fig. 141.

For small hollow mills some tool makers advocate three cutting teeth, while others claim better results with four teeth on all sizes.

The rear of the mill is bored somewhat larger than the cutting end, to allow it to clear on long cuts. The cutting end must be relieved or it will bind and rough the work, and probably twist it off in the mill. There are several methods of relieving mills; the more common one is to ream the hole tapering, making it larger at the back end, as shown in Fig. 140. Another method is to file back of the edges, as shown in Fig. 141.

For making hollow mills having the same outside diameter, it is advisable to use a holder of the form shown in Fig. 142, having a taper shank which fits the spindle of a lathe. The hole in the other end of the holder should be the size of the holder in the screw machine or turret lathe, which holds the mills when in use. The steel for the hollow mills should be cut to length and turned to the proper diameter to fit the holder. After putting the blank in the holder, the ends may be squared and the holes drilled and bored to the desired sizes. If the mill is to be of the form shown in Figs. 138, 139 and 140, the cutting end may be reamed with a taper reamer to give the necessary clearance. The reamer should be run in from the back end in order that this end of the hole be larger. For the form shown in Fig. 141, the hole at the cutting end should be straight and to finish size.

The mill is now ready for cutting the teeth. If four cutting edges are to be given, a side milling cutter may be used of a diameter about double the diameter of the hollow mill to be cut. The blank should be held in a chuck on the end of the spindle in the spiral head. For a strong tooth, the spiral head may be set at an angle that will produce a tooth as shown in Fig. 143, by feeding the milling cutter *through* the blank. If a deeper tooth is desired, the spiral head may be set so that the blank will be in a vertical position, and the milling cutter fed in until the desired form and depth of tooth is obtained.

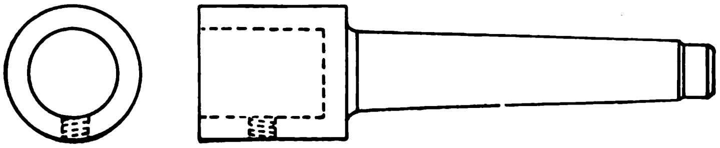


Fig. 142.

An Adjustable Hollow Mill may be made by following the instructions given for *solid* hollow mills, except that the mill must be split as shown in Fig. 144, in order that the size of hole in the mill may be altered. There are two methods of adjusting the mill: the outside of the cutting end of the mill is tapered, and a collar having a corresponding taper hole is forced on the mill. The collar closes it, and causes it to cut smaller. The other method is to turn the outside of the hollow mill straight, and close by means of the clamp collar shown in Fig. 145. As adjustable hollow mills are generally used for finishing cuts, and are not used when taking heavy cuts, the teeth may be made finer than those of solid mills used for roughing. The teeth being nearer together will finish a cylindrical piece more accurately than if the teeth were cut farther apart. It is customary to give adjustable hollow mills to be used for finishing from six to eight teeth. The cutting edges should be cut radial for most work. Better results will be obtained if the hole in the cutting end of the mill is left .005 inch small, and ground to size after the mill is hardened.

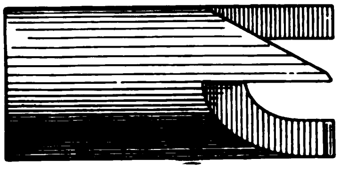


Fig. 143.

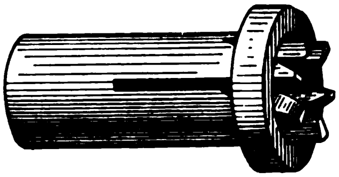


Fig. 144.

The hollow mill, whether it be solid or adjustable, should be hardened a trifle farther up than the length of the teeth, and drawn to a straw color. The mill is sharpened by grinding on the ends of the teeth.

Hollow Mill with Inserted Blades. For large work, hollow mills are made having inserted blades. The hollow mill with removable blades, shown in Fig. 146, does good service on rough work; the blades may be made of self hardening steel and inserted in a machine steel body. The grooves in the body to receive the blades should be milled with a cutter whose thickness corresponds to the size of the steel to be used for the blades. The grooves are cut somewhat deeper at the front end of the holder in order that the blades may have clearance to prevent binding. The edge of the slot corresponding to the cutting edge of the blade should be radial.

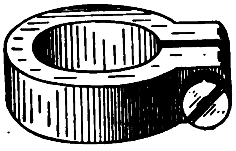


Fig. 145.

Two collars should be made of machinery steel having holes sufficiently large to allow their being placed on the mill when the blades are in the slots. Each collar should be provided with the same number of set screws as there are blades in the mill. One collar holds the blades in the holder, while the other is placed nearly at the ends of the blades to support them while cutting. This form of mill is used on cuts not exceeding one inch in length, as the blades must project beyond the holder to the desired length of the cut.

The size of cut may be changed somewhat by setting the cutters back or ahead in the slots, or paper may be placed in the slots under the blades to increase the diameter of the cut. The blades are set to an even length by bringing them against a surface perpendicular to the axis of the body of the tool.

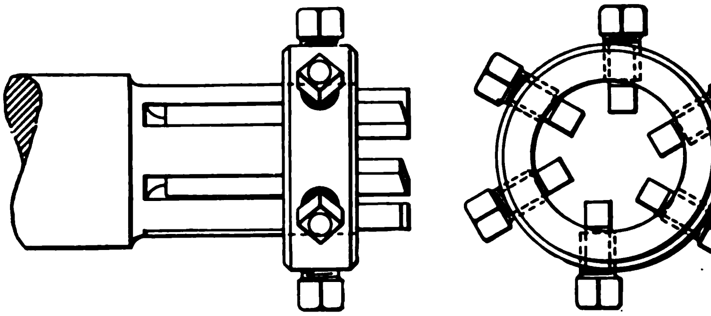


Fig. 146.

Hollow Mill with Pilot. It is often desirable to mill the outside of a projection central with a hole passing through it. This may be done very satisfactorily with a hollow mill having a pilot as shown in Fig. 147. It is advisable to hold the pilot in place by means of a set screw. In order to give clearance to the teeth to prevent the mill binding when cutting, the hole may be bored tapering .010 inch in $\frac{1}{2}$ inch of length, making it largest at the back end.

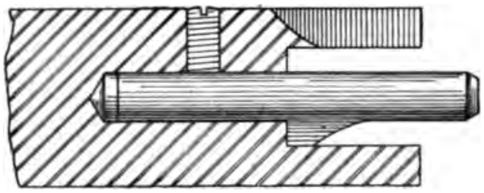
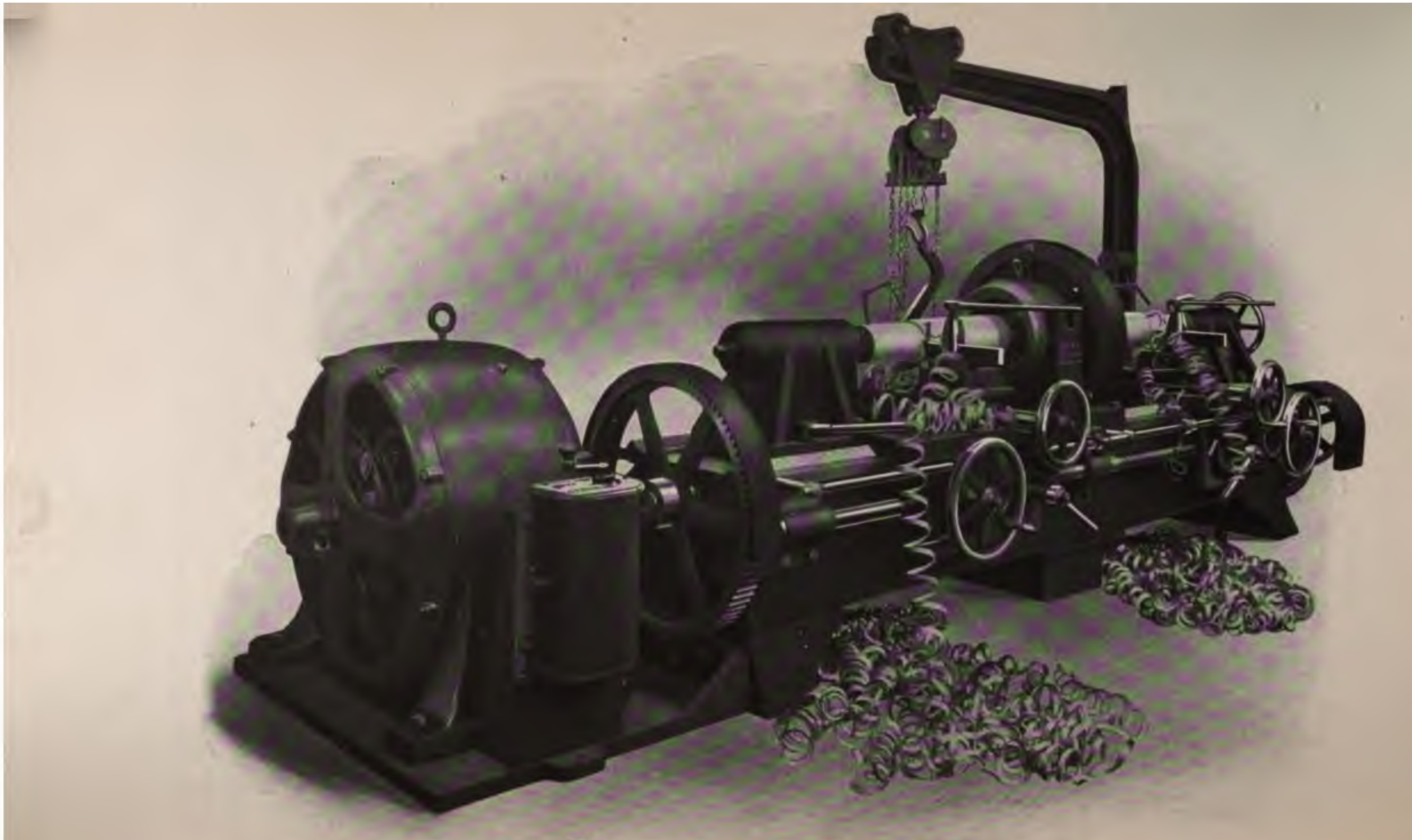


Fig. 147.

When hardening a mill of this description it is advisable to dip it in the bath with the cutting end *uppermost* working it up and down rapidly. After hardening, it may be drawn to a straw color. The pilot should be turned .010 inch above finish size, hardened, and drawn to a brown color, and ground to the desired dimensions.



DOUBLE-AXLE LATHE.

Niles-Bement-Pond Company.

FORMING TOOLS.

Forming tools are used when several pieces are to be made of exactly the same shape. They are particularly valuable for giving the desired shape to formed mills and similar tools and are extensively used in duplicating a given shape on work produced in the screw machine.

Forming tools are made flat and circular in shape. When used in the lathe for shaping milling machine cutters and similar tools they are generally made flat; for backing off formed milling machine cutters they are always made flat; for screw machines in duplicating a given shape they are made both flat and circular.

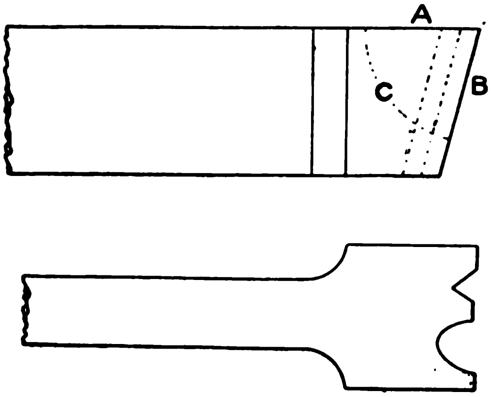


Fig. 148.

The flat forming tool is made as a solid cutter, the tool and shank being in one piece as shown in Fig. 148, or the cutter and shank may be made separate as shown in Fig. 149. When but one forming tool is to be made, that shown in Fig. 148 will be found to be inexpensive; but for making many tools, it will be found much cheaper to adopt the plan shown in Fig. 149.

On certain classes of work it is advisable to use a forming tool on a holder of the description shown in Fig. 150, which is known as a spring holder. On account of its design it may spring somewhat when used on heavy cuts, thus reducing the tendency to chatter. It is necessary to make these holders of tool steel, giving them a spring temper at point marked A. The slot

B allows the forming blade D to spring away from the work when under heavy strain. The blades may be planed up in long strips and cut off the required length. The tongue E should fit the slot O, which, with two cap screws through F and G, securely holds the blade in position.

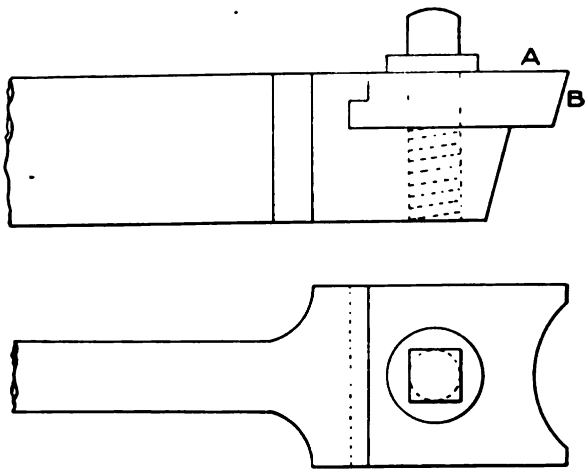


Fig. 149.

In order that a forming tool may cut readily, it is necessary to give the surface marked B a sufficient amount of clearance.

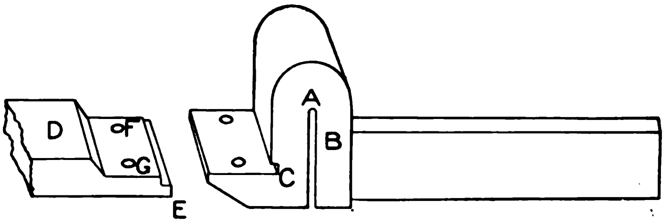


Fig. 150.

For tools to be used for shaping milling machine cutters and similar tools, a clearance of 10° to 15° will be ample; that is, the angle should be from 80° to 75°. But if the tool is to be used for backing off the teeth of formed milling machine cutters, it is necessary to give a clearance of 18° to 22°. When making a forming tool having the required angle at D, the shape can be produced by tipping the blank to the required angle and planing or milling with a tool having exactly the shape it is desired to produce. The tool used may be made of a shape enough different from that desired that it may produce the proper shape when the cutter is in a vertical position, and the blank at a given angle from that position as shown in Fig. 151. Or, the tool may be held in the tool post (or in a fixture made for the purpose) of the shaper or planer at the same angle as the blank being cut, as shown in Fig. 152, and it will produce a shape corresponding very closely with its own.

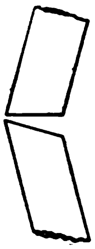


Fig. 151.

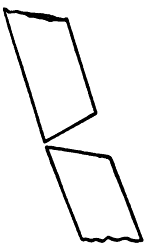
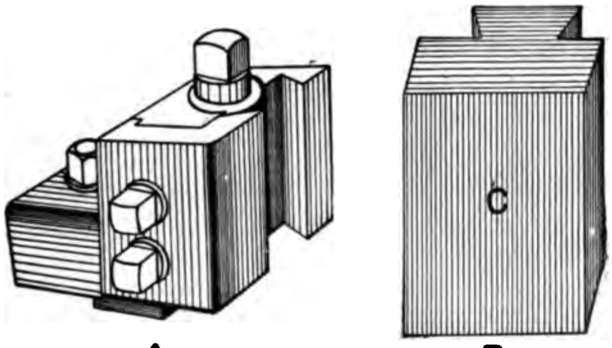


Fig. 152.

For screw machine and similar work for duplicating given shapes, a forming tool is made of the shape shown in Fig. 153. A represents a holder used by the Brown & Sharpe Mfg. Co. for use on their screw machines. B shows the forming tool blank. The desired shape is cut in the surface marked C.



A B

Fig. 153.

Circular Forming Tools are used very extensively on screw-machine and similar work. They are valuable on account of the ease with which any number of them may be produced, provided a forming tool is used in producing the shape on the face as shown in Fig. 154. After the blank has been formed to the desired shape, it may be milled as shown in Fig. 155 in order to provide a cutting edge. If it is desired to produce a shape on the piece being machined to correspond with the shape of tool, it is necessary to have the cutting edge radial as shown in Fig. 155. In order to feed the tool into the stock faster than can be done with the form shown in Fig. 155, it is given more clearance as shown in Fig 156. On a tool whose cutting edge is not radial and will not produce a shape corresponding to its own, it is necessary when cutting the edge with the rake shown in Fig. 156, to make the face of the tool slightly different in form from that desired.

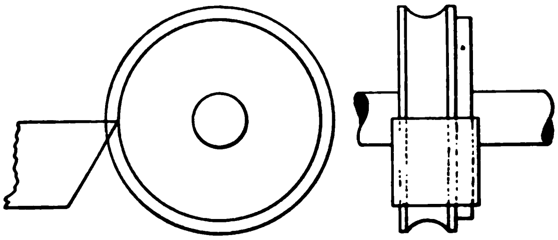


Fig. 154.

After milling the cutting edge, the name or number of the tool may be stamped on it, after which it is ready for hardening. When extremely high carbon steel is used, the tools sometimes crack while hardening from the strain incident to their shape. In order to overcome this tendency, some tool makers make two extra cuts in the edge as shown in Fig. 157, in order that the hardened edges may not be cracked from the contraction. Two cutting edges, as shown in Fig. 158 are often given tools in order that it may not need to be ground as often as when it has but one cutting edge. It is not necessary to stop the screw machine nearly as long to grind both cutting edges, as to stop the machine twice to grind the same edge on account of the time necessary to rig up the grinder.

When hardening, the tool should be heated to a low red and plunged in a bath of water or brine from which the chill has been removed; it should be worked around well in the bath. If the temper is not to be drawn after hardening, the tool may be held over the fire after removing from the bath and heated sufficiently to remove the tendency to crack from internal strains.

On account of some weak projection, which, because of its shape is likely to break when used, it is sometimes necessary to draw the temper. It is not always necessary to draw the temper to a straw color, and as a light straw is the first temper color visible, some other means must be employed. The tool may be placed in a kettle of oil, and by means of a thermometer any degree of heat may be obtained. The writer recalls a certain forming tool which was too brittle when left as it came from the hardening bath, yet was not hard enough when drawn to even the faintest straw color. When taken from the hardening bath, it was placed in a kettle of boiling water and left there about five minutes. The heat of the water at 212° reduced the brittleness

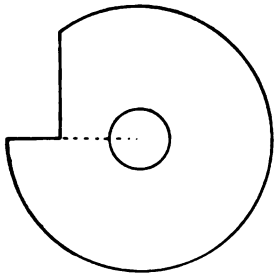


Fig. 155.

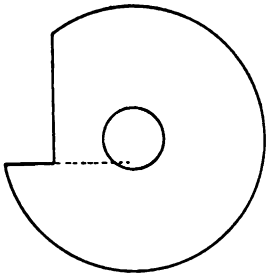


Fig. 156.

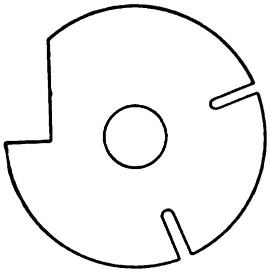


Fig. 157.

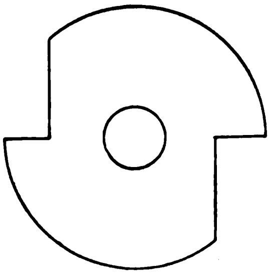


Fig. 158.

so that the tool stood up in a good shape, yet it did not perceptibly soften it.

The following is an excellent plan: Use a bath of water having about one inch of oil on top; the tool after being heated red hot is plunged down through the oil into the water. Enough oil adheres to prevent the sudden shock which the steel received when plunged into the cold bath.

"Pack Hardening" also gives excellent results.

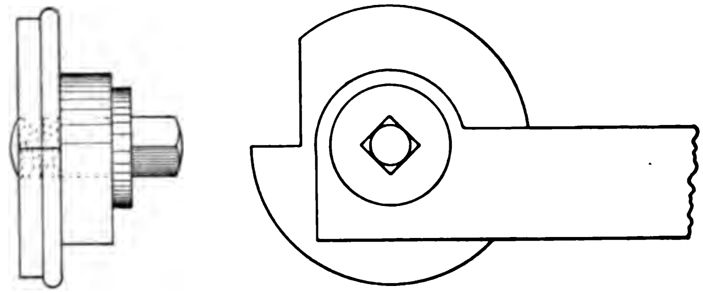


Fig. 159.

Tool Holders. The form of the holder for the tool depends on the class of work to be done and the machine in which it is to be used. Fig. 159 shows a design commonly used for hand screw machine work. If the cuts are comparatively light, the side of the tool and holder may be flat as shown. If, however, heavy cuts are taken which would have a tendency to turn the tool, it is often made with a taper projection on one side as shown in Fig. 160, the holder having a corresponding taper hole to receive the projection. This projection should be a good fit in the taper hole, but should not go in far enough to strike the bottom, neither should the side of the tool bear against the side of the holder.

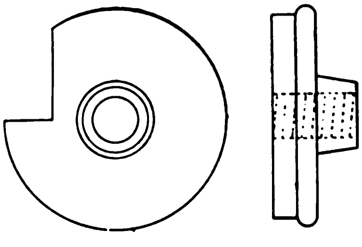


Fig. 160.

When used in holder is gener-
ally of a di machines.

A very common form is shown in Fig. 161. This holder is made in the form of an angle iron. The fixture (holder) is fastened to the tool rest by means of the bolt shown. The tool is fastened to the upright side of the holder by means of the bolt represented with its head let into the forming tool.

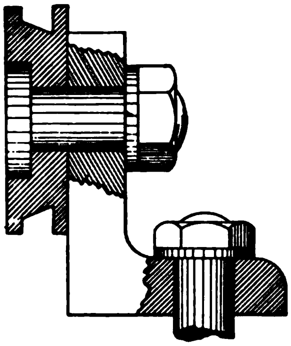


Fig. 161.

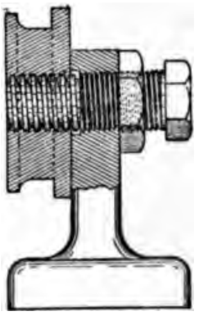


Fig. 162.

When extra heavy cuts are to be taken with a forming tool, it is sometimes considered advisable to make a holder of the form shown in Fig. 162. The holder is bolted to the tool rest in the same manner as the one represented in Fig. 161. A square thread having a pitch of five or six threads to the inch is cut in the forming tool; the thread should be right or left hand depending on which side of the machine the tool is to be located when in use, the thread being such that the tool will tighten by the pressure exerted by the cut. To get an adjustment, the thread in the holder must be of a finer pitch than that in the forming tool and of the same hand. If desired, this tool may be used in the ordinary form of holder shown in Fig. 161 by use of the bolt shown in Fig. 163.

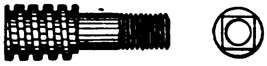


Fig. 163.

MILLING CUTTERS.

Milling machine cutters are made in two different forms: solid and with inserted teeth. It is customary in most shops to make cutters up to 6 or 8 inches in diameter solid, and above this size they are made with inserted teeth.

SOLID CUTTERS.

When making solid cutters it is advisable to use steel somewhat larger than the finish diameter of the cutter. A hole should be drilled in the blank $\frac{1}{16}$ inch smaller than the finish size of hole and the outside surface should be turned off. After annealing, it should be put in the chuck on the lathe, the hole bored and reamed to size and the hole recessed as shown at C in the sectional view of Fig. 164.

The piece should now be placed on the mandrel, and turned to the proper diameter and length. The teeth should be cut in the universal milling machine, or in a milling machine provided with a pair of index centers. The number of cutting edges for solid milling cutters varies somewhat according to the nature of the work to be done, but for general shop use the following table will be found satisfactory.

CUTTING EDGES FOR MILLING CUTTERS.

Diameter of Cutter.	No. of Cutting Edges.	Diameter of Cutter.	No. of Cutting Edges.
½	6	2½	20
¾	8	3	24
1	10 or 12	3½	26
1¼	14	4	28
1½	16	5	30
2	18	6	32

For most work it is desirable to have the faces of the teeth radial as shown in Fig. 164. However, when milling cutters are made to run in the direction of the feed or onto the work instead of against it, the teeth should be given a negative rake (cut ahead of the center) as shown in Fig. 165, as it has a tendency to keep the piece being milled from drawing toward the cutters.

When cutting the teeth, it is necessary to use a cutter that gives sufficient depth of tooth to provide a receptacle for chips, and also gives a form that supports the cutting edges. A cutter may be used that will produce an angle of about 50° between the face and back of the tooth as shown at A in Fig. 164. The cutter should cut deep enough to leave the lands about $\frac{1}{32}$ inch in width at the cutting edges.

The form of cutter shown in Fig. 164 is known as a Side Milling Cutter. When cutting the teeth on the sides, it is necessary to put the cutter on a plug whose upper end does not project much above the top face of the cutter; this plug may be made straight and held in the chuck on the end of spindle in the spiral head. Such a plug is shown in Fig. 166 inserted in the cutter. If *many* cutters are made with teeth on the sides, it is advisable to make an expanding arbor, Fig. 167, whose shank fits the taper hole in the spindle of the spiral head. When milling the teeth on the sides, the index head must be inclined a little so that the side of the mill will stand at a small angle from the horizontal in order that the lands of the teeth may be of equal width at each end. The amount of this inclination cannot readily be computed.

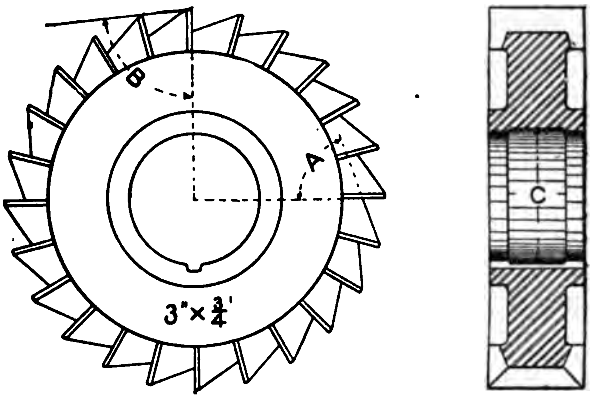


Fig. 164.

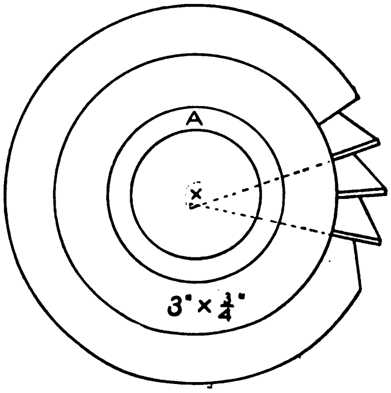


Fig. 165.

It is formed by first cutting a tooth leaving the cut somewhat shallow, then turning to the next tooth. After cutting the second tooth, the change in inclination will be apparent.

When the teeth are cut and the burrs removed, the diameter and length of the cutters may be stamped as shown in Fig. 164. The cutter is now ready for hardening. To successfully harden, it is necessary to have a *low, uniform* red heat; the teeth must be no hotter than the portion between the hole and the bottom of the teeth. When held toward the light there should be no trace of black in the interior of the cutter. When a uniform heat no higher than is necessary to harden the steel has been obtained, the cutter may be plunged into brine from which the chill has been removed; it should be worked around rapidly in the bath until the singing has ceased. It should then be removed from the brine and immediately plunged into oil and allowed to remain there until cold. When cold, the cutter may be taken from the oil and heated sufficiently to prevent cracking from internal strains. The cutter may now be brightened and the temper drawn to a straw color.

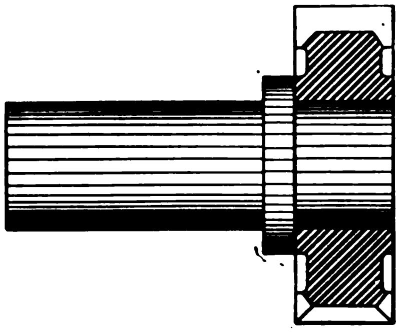


Fig. 166.

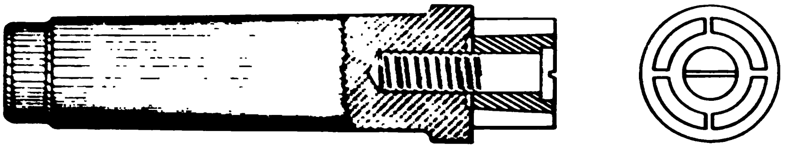


Fig. 167.

Grinding the Hole to Size. It is customary to ream the holes in milling cutters to size, and if the cutter contracts in hardening, the holes are brought to size again by lapping with a lead or cast iron lap, by means of oil and emery. However, this operation does not provide for the enlarging of the hole. While this is an unusual occurrence, it *sometimes* happens, and as a consequence the cutter does not fit the milling machine arbor and cannot do as good or as much work as it should.

On account of the necessity of having a correct fit on the milling machine arbor, it is advisable to ream the hole of the cutter with a reamer about .005 inch under the size of the arbor and finish by grinding after the cutter is hardened.

When grinding the hole to size, the cutter may be held in a chuck and ground with a small emery wheel, using the internal grinding attachment as shown in Fig. 168. This attachment is

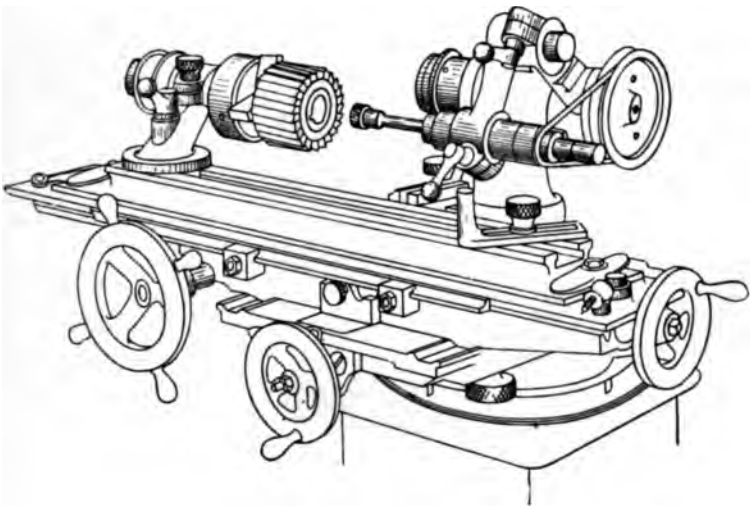


Fig. 168.

so designed that it may be swung out of the way when gauging the size of the hole as shown in Fig. 169. After grinding the hole to size it is advisable to grind the shoulders on each side of the cutter straight and true with the hole in order to prevent any possibility of springing the milling machine arbor by any untruth on the part of the cutter, and to prevent any possibility of the cutter running out of true. The shoulder (or boss) referred to is shown in A, Fig. 164.

There are two methods of grinding the shoulders. By one method the outer shoulder and the hole are ground at the same setting; if this is done properly this shoulder will be true with the hole. The chuck is now removed from the grinder and a face plate having an expanding plug is put in its place. The shoulder that has been ground is placed against the face plate with the expanding plug in the hole of the cutter. The outer shoulder may be ground after the plug is expanded until the cutter is held rigidly in place against the face plate which should run perfectly true.

By the other method both shoulders are ground while on an arbor which is necked down each side of the cutter as shown in Fig. 170. This necking allows the wheel to traverse the whole length of the shoulder and not cut into the arbor, as would be the case if an ordinary mandrel were used.

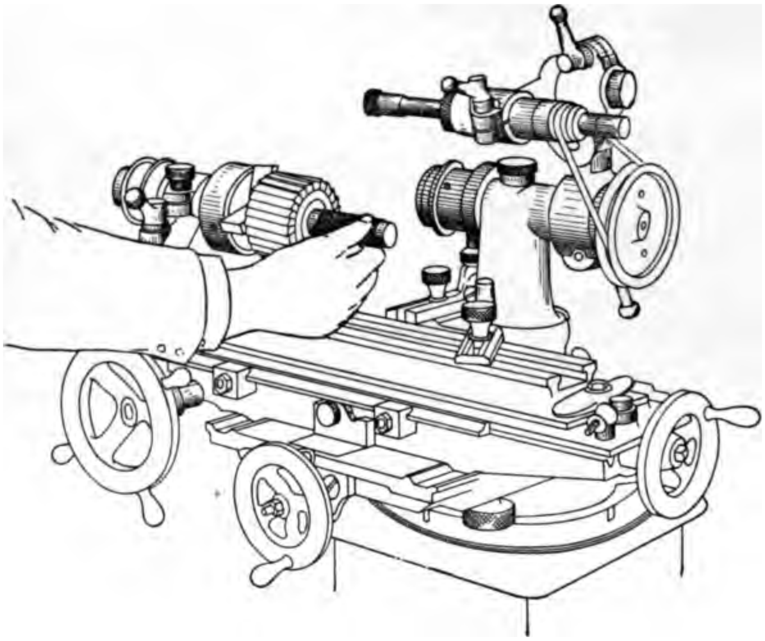


Fig. 169.

Grinding. In order to get the best results from a milling cutter it is necessary to use some form of grinder having a means of properly locating each tooth as it is presented to the wheel. This is usually accomplished by a finger which may be adjusted to the proper height to produce the required amount of clearance. The teeth may be given a clearance of about 3° as shown at B, Fig. 164. With this amount of clearance the cutter works freely and retains its edge; if more clearance is given the cutter is likely to chatter, and the edges of the teeth will become dull rapidly.

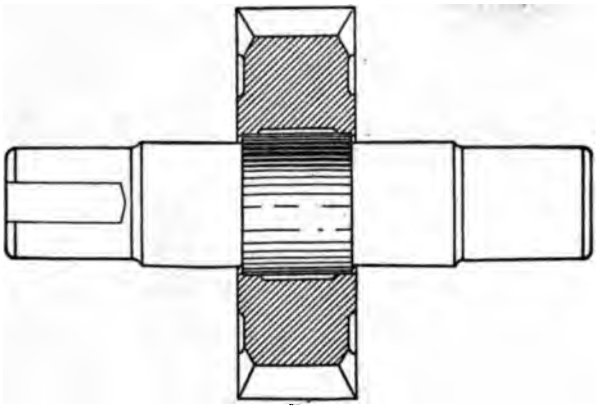


Fig. 170.

Fig. 171 shows a cutter in position for grinding the teeth; it will readily be seen that the tooth being ground rests on the finger or tooth rest; this finger may be adjusted to give any desired amount of clearance to the tooth. For grinding the teeth on the *side* of a milling cutter, a small emery wheel may be used in order to get the necessary amount of clearance without touching the tooth next to the one being ground.

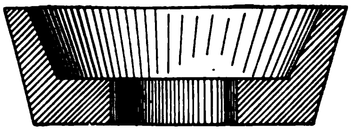


Fig. 172.

If a grinder is used which will take a cup wheel as shown in Fig. 172, and whose table can be turned to bring the cutter in the position shown in Fig. 173, a form of clearance is given the tooth which is more satisfactory than if ground with a small wheel. With the cup wheel the line of clearance is straight, while with the small plain wheel it is hollowed out, and as a consequence the cutting edge is weak.

Spiral Milling Cutters. It is customary in most machine shops to make all milling cutters of more than ½ inch face with teeth cut spirally as in Fig. 174. The amount of spiral given the teeth varies in different shops and on different classes of work.

The object of providing spiral teeth is to maintain a uniformity of cutting duty at each instant of time. With teeth parallel to the cutter axis, the tooth on meeting the work will take the cut its entire length at the same instant, causing a jump to the work on account of the springing of the device holding the work, and of the cutter arbor. If the teeth are cut spirally, the cut proceeds gradually along the whole length of the tooth, and after the cut is started a uniform cutting action is maintained, producing smoother work and a truer surface, especially in the case of wide cuts.

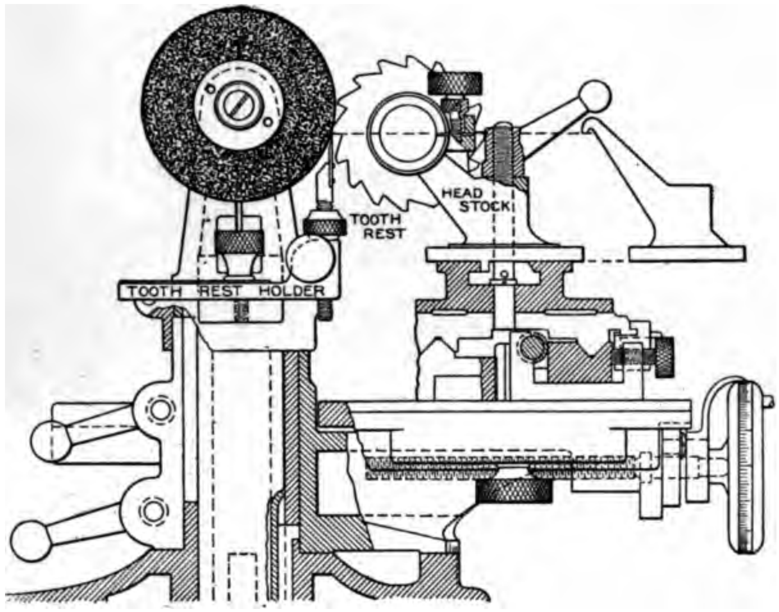


Fig. 171.

Milling cutters may be cut with either a right or left hand spiral, or helix, although it is generally considered good practice to cut a mill having a wide face with a spiral that will tend to force the cutter arbor into the spindle rather than to draw it out; then again, it is better to have the cutting action force the solid shoulder against the box, rather than to draw the adjusting nut against the box.

Where two very long mills are used on the same arbor and it is found necessary to cut them with a quick spiral, one cutter is sometimes cut with a right hand spiral and the other with a left hand spiral, in order to equalize the strain and reduce the friction resulting from the shoulder of the spindle pressing so hard against the box.

Special care should be taken in cutting spiral milling cutters that the work does not slip. When a cut has been taken across the face of a cutter it is best to lower the knee of the milling machine, thus dropping the work away from the mill while coming back for another cut; the knee can then be raised to its proper position which may be determined by means of the graduated collar on the elevating shaft of the machine.

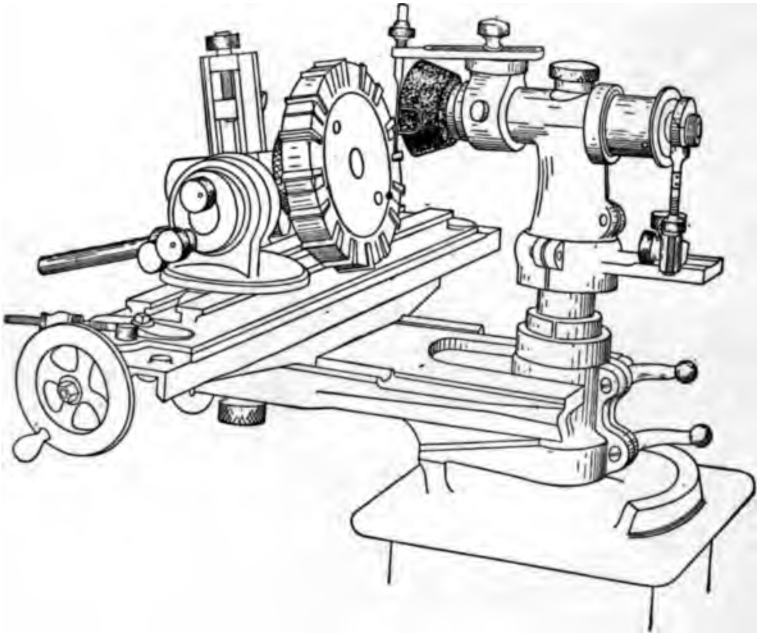


Fig 173.

As it is important that the face of the cutting tooth be radial and straight, it will be found necessary to use an angular cutter of the form shown in Fig. 175, as cutters of this form readily clear the radial face of the cut and so remain sharp longer and produce a smoother surface to the face of the tooth than if cut with an angular cutter of the form used for cutting teeth which are parallel to the cutter axis.

The angular cutters for spiral mills are made with either 40°, 48° or 53° on one side and 12° on the other.

By setting the cutter, as shown in Fig. 175, so that the distance A is one twelfth the diameter, the face cut by the 12° side of the angular cutter will be nearly radial for the usual proportions.

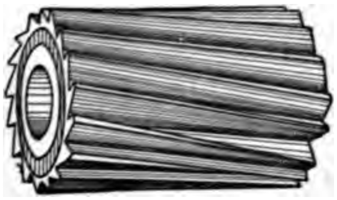


Fig. 174.

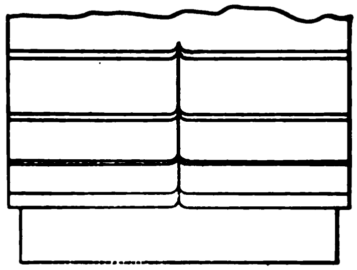


Fig. 176.

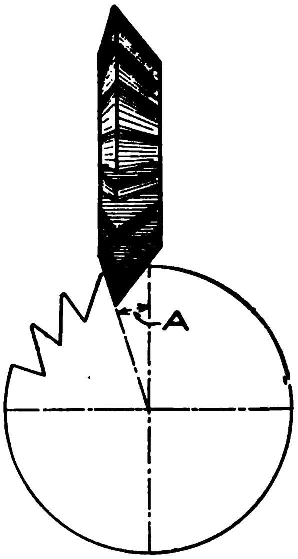
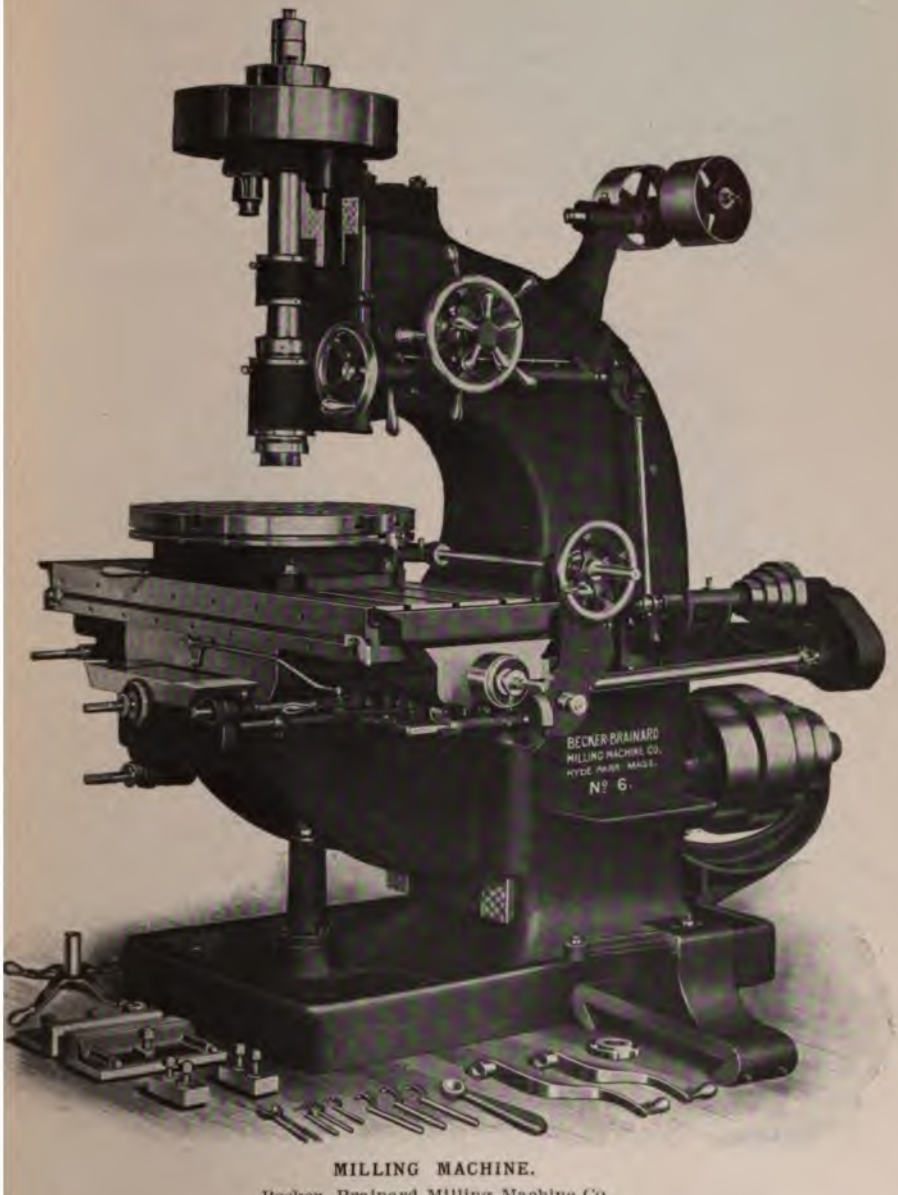


Fig. 175.

The setting for cutting the teeth of a spiral cutter must be made before turning the spiral bed to the angle of the spiral.

Milling Cutters with Interlocking Teeth. When two milling cutters of an equal diameter are to be used on the same arbor in such a manner that the end of one cutter is against the end of the other, the corners of the cutting teeth are likely to break away leaving a projection — or fin — on the work as shown



MILLING MACHINE.
Becker, Brainard Milling Machine Co.

in Fig. 176. In order to overcome this, part of the teeth are cut away on the sides of the cutters; that is, a tooth will be cut away on one cutter and the corresponding tooth on the other cutter will be left full length to set into the recess formed by the cutting away of the tooth. In some shops it is customary to cut away every other tooth while in others two, three or four teeth, will be cut away and an equal number left. Fig. 177 represents a pair of mills having every other tooth cut away, while Fig. 178 represents a pair having four teeth cut away.

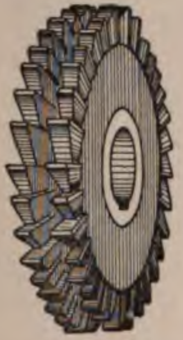


Fig. 177.

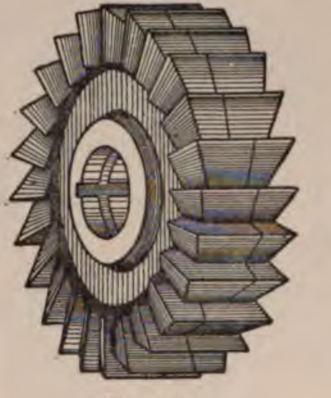


Fig. 178.

In order to cut away the teeth to make the cutter of a form having interlocking teeth, the cutter should be placed on a plug or expanding arbor as described for milling teeth on sides of side milling cutters. By means of a milling cutter having the proper width, the teeth may be milled away, although in case a cutter having several teeth cut away as shown in Fig. 178, it is well to use a narrow cutter and after taking one cut turn the index head so that the next tooth is in position. Continue doing this until the desired number of teeth are cut away. The index head may now be turned to pass over the required number of teeth and the operation repeated.

It is necessary when making cutters with interlocking teeth (sometimes called dodged-teeth) that the milling be deep enough to prevent the corresponding tooth on the other part of the cutter from striking the bottom of the recess. The parts of the cutter should bear against each other on the shoulders, or hubs.

An excellent form of milling cutter to be used for milling slots or similar work may be made as shown in Fig. 179. This form is less expensive to make than one having interlocking teeth and answers the purpose as well. It is necessary to make an eccentric mandrel of the design shown in Fig. 180 having the eccentric centers on opposite sides of the regular

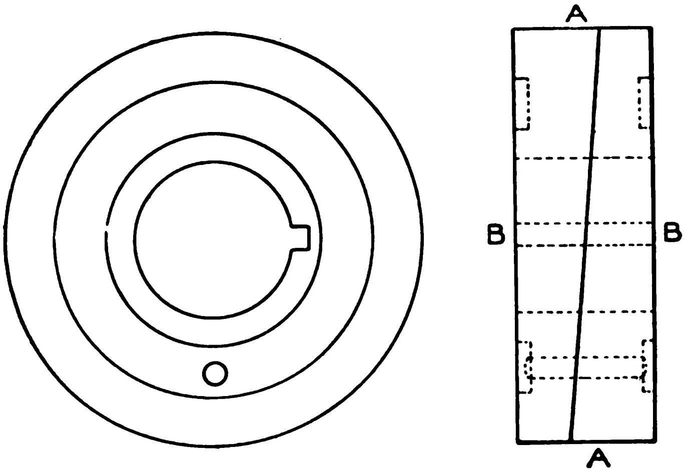


Fig. 179.

centers as shown. The two pieces which make the cutter should be cut from the bar long enough to finish the thickness of the heaviest part A A, Fig. 179. The hole is made $\frac{1}{16}$ inch smaller than finish size, the outside surface turned off and the pieces annealed.

After annealing, the hole may be made the desired size for grinding. One of the pieces may then be placed on the eccentric mandrel, forcing it on until the side that is to be beveled is exactly in the center of the mandrel. The side B may be machined with the mandrel running on the regular centers while the beveled side must be machined with mandrel running on the eccentric centers. When the arbor is running on these centers, a distance half way between the two ends runs true; it is at this point that the side of the blank to receive the bevel should be located as shown in Fig. 181 provided the eccentric centers are of an equal depth. After machining the two parts of the cutter to shape, they should be so placed on a stud that the two beveled sides will be next each other as shown in Fig. 179, and the thinnest part of one next to the thickest part of the other. The pin hole may now be drilled and reamed for a $\frac{3}{16}$ inch pin which should be inserted. The blank is next placed in the vise on the shaper or planer and the spline slot cut as shown. It is now ready to be milled. After the cutter is hardened, the beveled sides may be ground true, the halves put together, hole ground to size, and the cutter ground to thickness, after which the teeth may be ground for clearance. If it is found necessary to increase the width of the slot, it may be done by shimming between the two parts of the cutter with paper or thin sheet metal; the design of the cutter allows this to be done without leaving any *fin* in the slot.

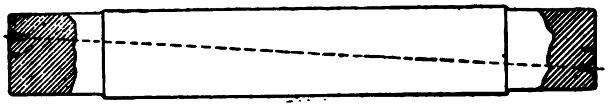


Fig. 180.

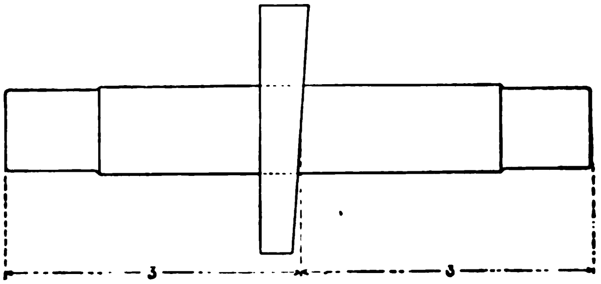


Fig. 181.

Nicked Teeth. Spiral cutters with nicked teeth, Fig. 182, are especially adapted for heavy milling. As the chip is broken up a much heavier cut can be taken than would be possible were an ordinary cutter used. The nicking may be done as follows: An engine lathe may be geared to cut a thread of the required pitch — two threads to the inch will be found satisfactory — and with a round nose tool $\frac{1}{8}$ inch wide cut a thread of sufficient depth that it may not grind out before the teeth will become too shallow to allow further grinding. This thread should be cut before milling the spaces to form the teeth.

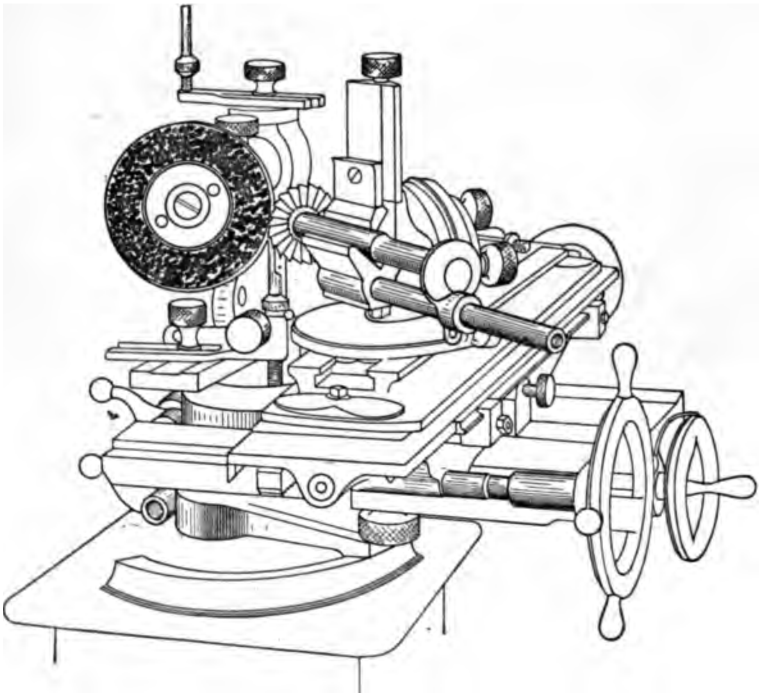


Fig. 183.

Angular Cutters. When making angular cutters the same general instructions given for making solid straight cutters should be followed except that the desired angle should be given.

When milling the spaces which form the teeth, the index head is set at an angle that will cut the edge of the tooth of an equal width its entire length. After removing the burrs the cutter may be hardened and tempered. The hole should be ground to size and the sides ground true with the hole. It should then be placed on a mandrel or stud and the teeth ground for clearance. Fig. 183 shows the method used in grinding the teeth of a mill of this form.

MILLING CUTTERS WITH INSERTED TEETH.

When milling cutters exceed 6 or 8 inches in diameter, it is generally cheaper to make the body of cast iron or machinery steel and insert in the periphery teeth made of tool steel. There is a variety of methods for holding the teeth in place. If the cutter is narrow, or is to be used as a side milling cutter, the grooves to receive the teeth may be cut straight (parallel to the cutter axis) as shown in Fig. 184. If the cutter face is over one inch long, the slots to receive the teeth should be cut in such a manner that spiral teeth may be used.

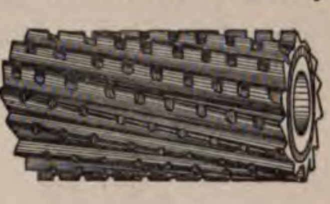


Fig. 182.

While it is a comparatively easy matter to cut the slots spirally, it is difficult to make the teeth of a shape that will fit the spiral slots without the aid of special tools. Consequently the slots are generally milled at an angle to the cutter axis, having the side of slot that corresponds to the face of the tooth equidistant from a radial line at each end of the cut. The face of the

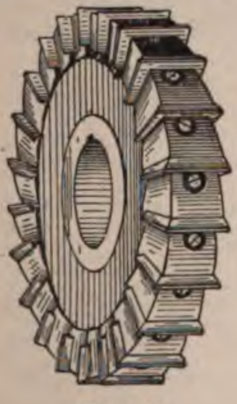


Fig. 184.

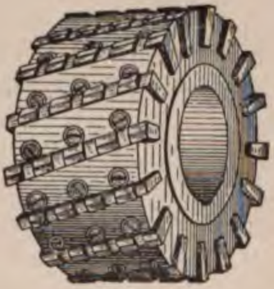


Fig. 185.

slot at one end would be ahead of the center, while at the opposite end it would be behind the center; this is termed a front rake, and a negative rake respectively.

The slots should be cut somewhat wider than would be necessary were the teeth to be made of a spiral form. After turning to size, the faces of the teeth may be milled spirally to make them radial.

If the mills are intended for heavy work, the teeth may be nicked as already described. The coarse pitch thread should be cut before the teeth are milled spirally.

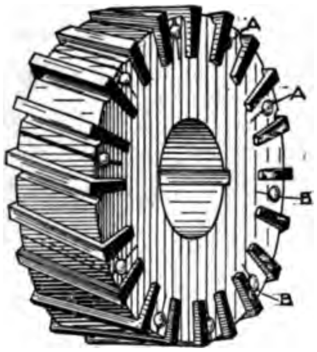


Fig. 186.

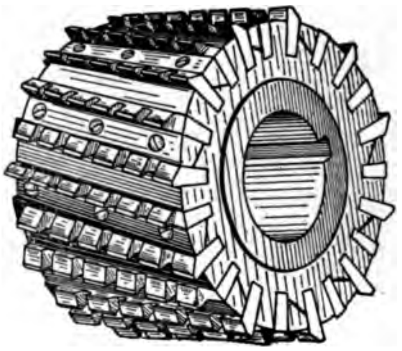


Fig. 187.

After hardening, the teeth may be put in place and fastened; they are now ready for grinding. The emery wheel for grinding milling machine cutter teeth should be of the proper grade as to hardness and coarseness; if the wheel is very *hard* or *fine*, it will be likely to draw the temper at the cutting edges of the teeth; the emery should not be coarser than No. 60 or finer than No. 90.

If the face of the wheel is glazed, remove the glaze with a piece of emery wheel somewhat harder than the wheel in use; this not only removes the glaze but makes the surface of the wheel more open and less likely to glaze. The emery wheel should run *true;* its face should not exceed $\frac{1}{4}$ inch in width. Generally speaking, the softer the emery wheel the *faster* it should run, but the peripheral speed should not exceed 5,000 feet per minute.

Fastening. There are several methods for fastening the teeth in this form of cutter, any one of which gives satisfaction if the work is well done.

The method illustrated in Fig. 186 is in use in the works of the Pratt and Whitney Co., of Hartford, Conn. In this design, between every second pair of teeth a hole is drilled and reamed taper to receive the taper pins A A, after which the slots B B are cut with a thin cutter. After the cutters are in place the taper pins A A are driven into the holes, thus locking the cutters. To remove the cutters the pins are driven out.

A method of fastening the cutters which are used by the Morse Twist Drill & Machine Co., of New Bedford, Mass., is shown in Fig. 187. In this case the stock between every second pair of teeth is milled away not as deep, however, as the slots for the cutters. Wedge-shaped pieces of steel are fitted between the teeth as shown. When these are drawn to place by means of fillister headed screws they bind the cutters very securely. If the wedge-shaped binding blocks touch the bottoms of the slots they will not hold the cutters securely in place.

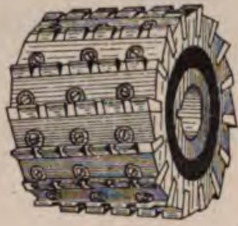


Fig. 188.

The method shown in Fig. 188 is used by Brown & Sharpe Mfg. Co. of Providence, R. I. The teeth are held in place by taper bushings and screws as shown.

Standard Key Ways. To prevent milling machine cutters turning on the arbor when cutting, it is necessary (especially when taking heavy cuts) to have key ways cut as shown in Fig. 189.

The arbor, of course, must have a similar slot to receive the key. It will be noticed that the dimension D refers to the diameter of the *hole* in cutter, and not to the diameter of the *cutter*.

Formed Cutters. As used by the Brown & Sharpe Mfg. Co., the term "Formed Cutter" applies to the cutters with teeth so relieved that they can be sharpened by grinding without changing their form. However, the term "Form Cutter" can be applied to any cutter cutting a form regardless of the manner in which the teeth may be relieved. Fig. 190 represents a formed cutter.

Formed cutters are used in many shops where work of irregular shape is milled in large quantities, as in sewing machine, gun and bicycle shops.

While this style of cutter can be made to better advantage in a shop equipped with machinery designed especially for this class of work, an ordinary engine lathe can be converted to a *backing-off lathe* for relieving or backing off the cutters. Or, a comparatively inexpensive fixture (known as the Balzar backing-off device) may be used. However, a simple arrangement consists of an eccentric arbor operated by a hand lever, or a stud may be screwed in the faceplate of a lathe; the cutter is placed on this stud in a position that allows the teeth to be given the necessary amount of clearance. When backing off the teeth of cutters whose faces do not exceed 1 inch in width the Balzar backing-off fixture shown in Fig. 191 can be used to advantage. This device

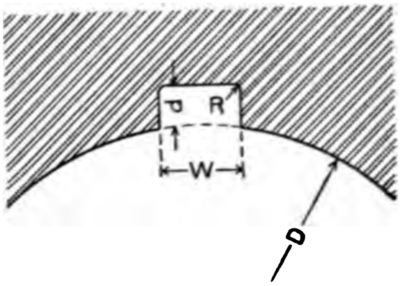


Fig. 189.

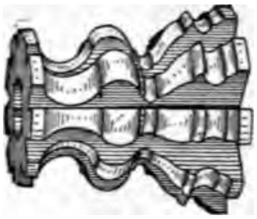


Fig. 190.

STANDARD KEY WAYS FOR CUTTERS.

Diameter (D), Inches.	Width (W), Inches.	Depth (d), Inches.	Radius (R), Inches.
3/8 to 9/16	3/32	3/64	.020
5/8 to 7/8	1/8	1/16	.030
15/16 to 1 1/8	5/32	5/64	.035
1 3/16 to 1 3/8	3/16	3/32	.040
1 7/16 to 1 3/4	1/4	1/8	.050
1 13/16 to 2	5/16	5/32	.060
2 1/16 to 2 1/2	3/8	3/16	.060
2 9/16 to 3	7/16	3/16	.080

is held between the centers of a lathe in the ordinary manner, the backing off being such that the cutter can be ground without alteration of shape. The tool is so constructed that it is only necessary to place the cutter upon the arbor in the ordinary way. Place the arbor on the lathe centers as shown, start the lathe and feed the forming tool in by the cross-feed screw in order to take

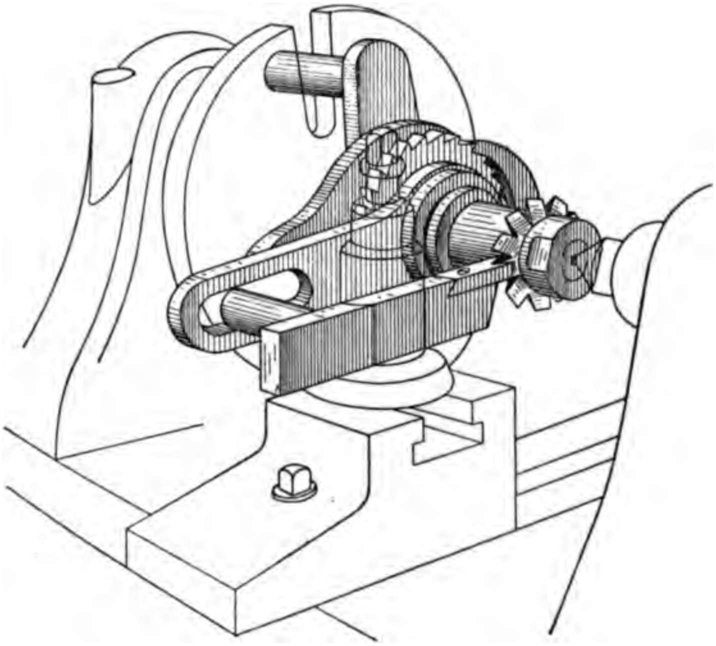


Fig. 191.

the desired cut in the same manner as in plain turning. The ratchet connected with the arbor, and actuated by the pawl, contains ordinarily thirty-six teeth and the stroke can be set to back off a cutter with 9, 12, 18 or 36 teeth.

Backing off by an Eccentric Arbor. An arbor may be made having a pair of centers located to give the cutter tooth the required amount of clearance; such an arbor is shown in Fig. 192. The eccentric centers are shown at the sectional portions at the ends. The amount of eccentricity depends somewhat on the size of the cutter to be backed off; but for cutters not exceeding 4 inches diameter, from $\frac{3}{16}$ to $\frac{1}{4}$ inch will give excellent results.

The screw at the end of the arbor should be of a fine pitch; about 12 threads per inch for arbors 1 inch diameter. The object in cutting a fine pitch thread is, the cutter being backed off may be held more securely with the same amount of power exerted in tightening the nut; again the depth of thread is not as great as for a thread of coarser pitch, and as a consequence, the plane portion at the end of the arbor (which is made the size of the bottom of the thread) may be left large enough to get in a center hole of good size having $\frac{1}{4}$ inch eccentricity.

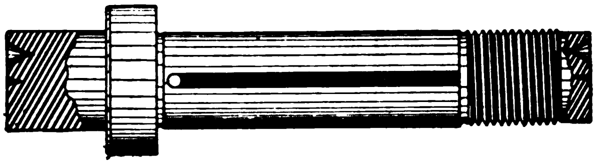


Fig. 192.

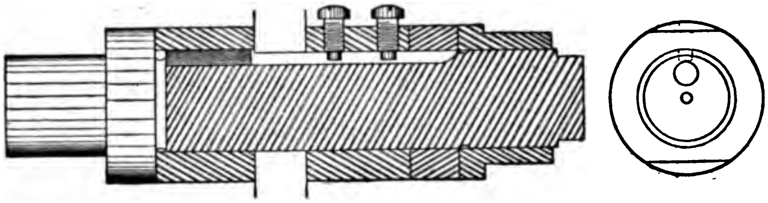


Fig. 193.

The spline cut should be at least $\frac{1}{8}$ inch wide and about $\frac{1}{8}$ inch deep; the walls of the cut should be parallel in order that the screws shown in Fig. 193 as passing through the collar and entering the slot in the arbor, may have a good bearing. These screws are to keep the collar from turning when the necessary power is applied to the nut when fastening the cutter in place. The collar on the opposite side of the cutter has a spline cut the same width as cut in the arbor, and is held in position by a spline as shown. The cutter cannot be held by a spline as it is necessary to move it each time a tooth is brought into position for backing off.

When machining the cutter blank, it is given the desired shape by means of a forming tool. If the shapes vary much in size the shape may be roughed out before using the forming tool. After it has been machined to the desired size and shape, it may be placed between the centers of the milling machine, and a number of grooves cut the entire length of the cutter. The number of grooves must correspond to the number of teeth the mill is to have; these grooves cannot be cut to finish width until after the teeth are backed off, because the forming tool cuts a trifle deeper at the point of contact, making it necessary to mill a small amount from the face of the tooth after backing off. The grooves are sometimes cut with a thin milling cutter, or a metal slitting saw $\frac{1}{8}$ inch thick. When a groove of this description is cut, the cutter has the appearance shown in Fig. 194. Cutting a groove of this form makes more work for the operator than when cut as shown in Fig. 195, in which the distance across the tops of the teeth is decreased by using an angular cutter of the shape shown in Fig. 196. After cutting the grooves the cutter may be placed on the eccentric arbor which is held between the centers of the lathe in the ordinary manner. A forming tool that will produce the desired shape of tooth is placed in the tool post; the top face of the tool must be set at the exact height of the center of the lathe in order to produce the proper shape. Fig. 197 shows an eccentric arbor

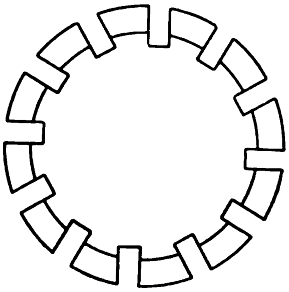


Fig. 194.

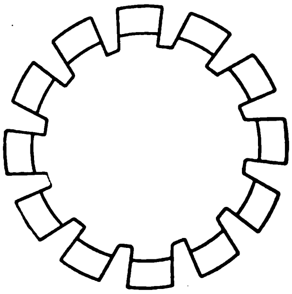


Fig. 195.

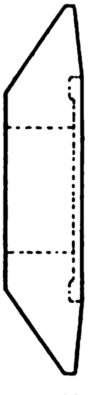


Fig. 196.

in a lathe in position to back off the teeth of a formed mill. The arbor is operated by means of the lever. The arbor is entirely independent of the spindle in its action, the eccentric centers being placed on the centers of the lathe, and the necessary motion given by means of the lever which strikes the carriage at the end of the stroke. In order to avoid bruising the lathe a strip of leather is attached to the lever as shown.

To set the cutter tooth in the proper location before backing off, a piece of thin sheet metal is placed on the top face of the tool, as shown in Fig. 198. The lever is brought down on to the carriage, the tooth of the cutter is brought down on to the sheet metal and the nut tightened. The tooth to be backed off is the one below that set to the thickness of the strip above the tool. The object in raising the tooth a given distance above the face is to prevent the one being backed from and striking the tool at the end of stroke. Again the teeth are set alike. This operation must be repeated for the setting of each tooth before backing off. The forming tool is fed by means of the cross-feed screw, a tooth

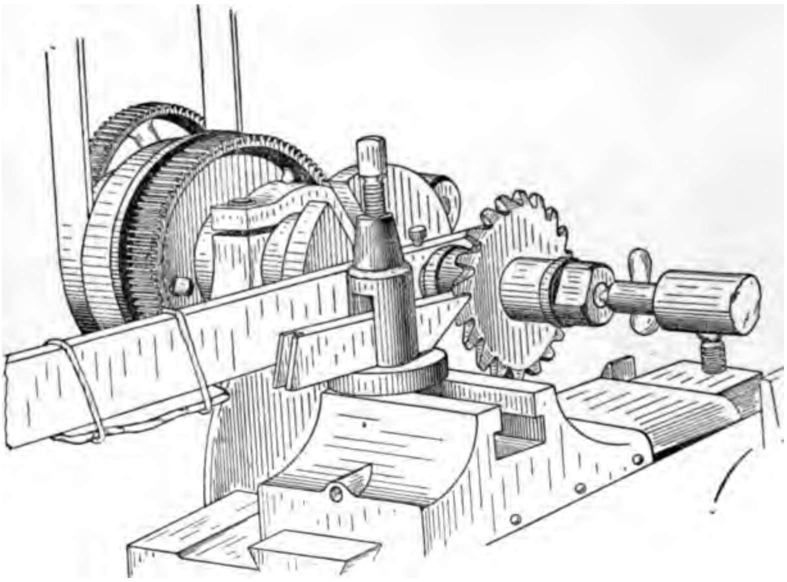


Fig. 197.

is backed off nearly the desired amount leaving a little for a finish cut; the tool is withdrawn, the nut loosened and the cutter turned on the arbor to bring the next tooth in position to be backed off. This operation may be repeated until all the teeth are backed off alike. The amount of backing off must be determined by the cross-feed stop, or a graduated dial on the cross-feed screw. After the roughing cut has been taken on all the teeth, the forming tool may be sharpened by grinding, or by oil stoning, and the finish cut taken on the teeth. Another method of backing off cutter teeth is shown in Fig. 199. A stud is screwed in the faceplate of a lathe near the outer edge as shown. The cutter which must be a fit on the stud is clamped by means of the nut shown. The finger A is movable in the slot in the stationary block B which is located on the face plate to bring the tooth to be backed off in its proper location, and keeps it from turning when being operated on. The forming tool is fed in gradually until the tooth is formed. finger is then disengaged from the space in the cutter, which lved by means of the set screw until the next is in position.

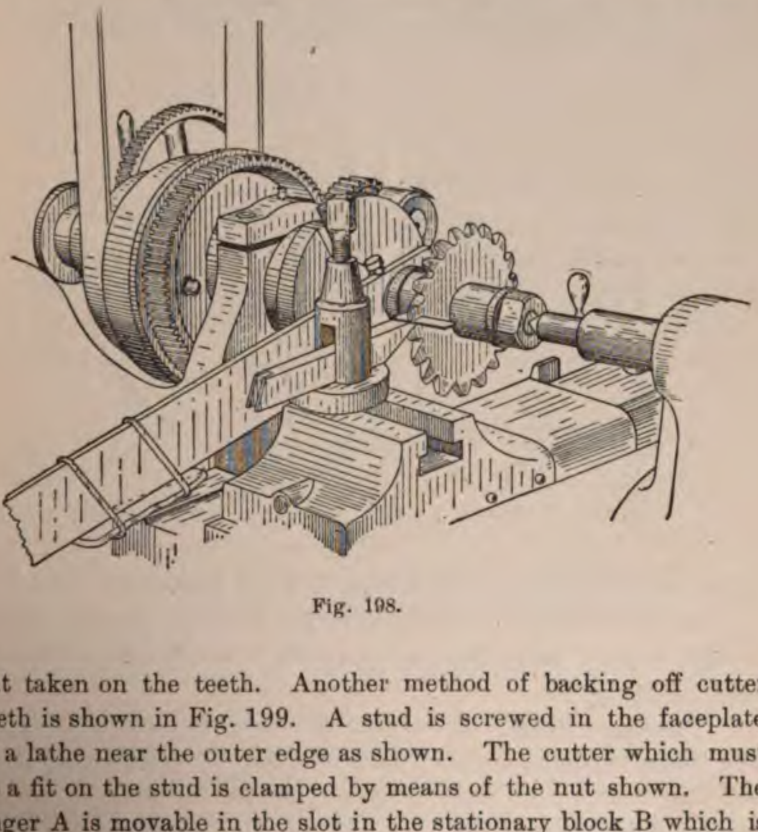


Fig. 198.

Each tooth is machined seperately, that is, the forming tool is fed in the required distance for each tooth when it is in position. The cutter is turned until the next tooth is in position, and the process repeated until each tooth has been backed off.

In backing off cutters in this device it is necessary to cut the notches (spaces between the teeth) somewhat wider than the teeth.

When backing off the teeth for clearance by any of the means described, it is first necessary to form the blank, then gash it or cut the notches as described; the teeth are now backed off.

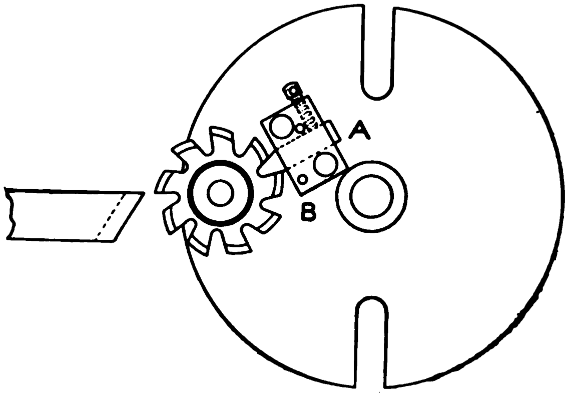


Fig. 199.

After backing off it is necessary to mill the face of the tooth back $\frac{1}{32}$ inch or so to cut away "the jump" (as it is termed) caused by the forming tool drawing in a trifle when it first strikes the edge of the tooth.

Threaded Holes. It is often necessary to make milling cutters with threaded holes. This happens in the case of *small* angular cutters, and many styles of cutters for use on profiling (edge milling) machines.

The same general instructions for making the other forms of cutters apply to those with threaded holes, except that instead of reaming the hole to a given size the thread is cut with a tap of the proper size and pitch or it is chased in the lathe. After threading, the cutter should be screwed on to a threaded arbor.

Fig. 200 shows an arbor of this description. The end A is threaded slightly tapering for short cutters about .002 inch in 1 inch of length. On the taper end of the arbor a thread should be cut of a size that will not allow the cutter to screw on the arbor quite the entire length, that is, the cutter should overhang the threaded portion of the arbor a trifle (say one thread); this allows the outer end to be squared up without mutilating the threads on the arbor. The reason for using the *taper* end of the arbor when squaring the first end of the cutter is that the shoulder is true with the thread in the cutter. After squaring this shoulder, the cutter blank may be removed and placed on the opposite end of the arbor with the side that has been squared against the shoulder of the arbor. This method of machining pieces of work having a threaded hole, where it is desirable that the outer surfaces be true with the hole, is applicable to all classes of work. The cutter may be machined to length and shape on the straight end of arbor.

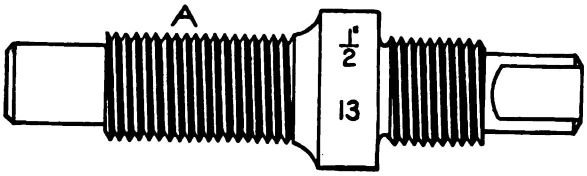


Fig. 200.

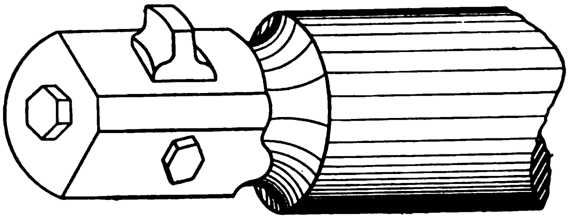


Fig. 201.

Fly Cutters. The simplest form of milling machine cutter is known as a fly cutter. It has only one cutting edge but is particularly valuable when making but one or two pieces of a kind for experimental work, and when making and duplicating screw-machine and similar tools of irregular shape.

As these cutters have but one cutting edge, they produce work very accurate as to shape, but cut very slowly and do not last as long as those having more teeth. However, they are used on *special work* on account of the small cost of making. It is necessary to hold the cutters in a *fly cutter arbor* which is shown in Fig. 201.

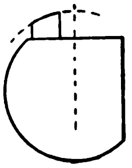


Fig. 202.

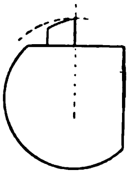


Fig. 203.

The cutter to be used in a fly cutter arbor may be filed to a templet, 'giving the necessary amount of clearance in order that the back edge, or keel, may not drag. If it is desirable to make the impression in the fly cutter with a milling cutter of the regular form, the piece of square steel from which the cutter is to be made may be held in the milling machine vise and the shape cut with the milling cutter. The desired amount of clearance may be given by holding the piece in the vise at an angle of a few degrees.

To make a fly cutter from a forming tool, the piece of steel may be held in the fly cutter arbor in such a position that the face is somewhat back of a radial line as shown in Fig. 202. After hardening the cutter may be set so that the cutting edge will be radial and the clearance will be as shown in Fig. 203.

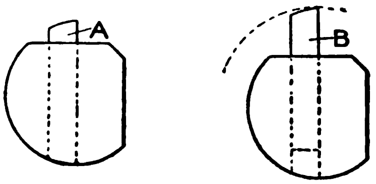
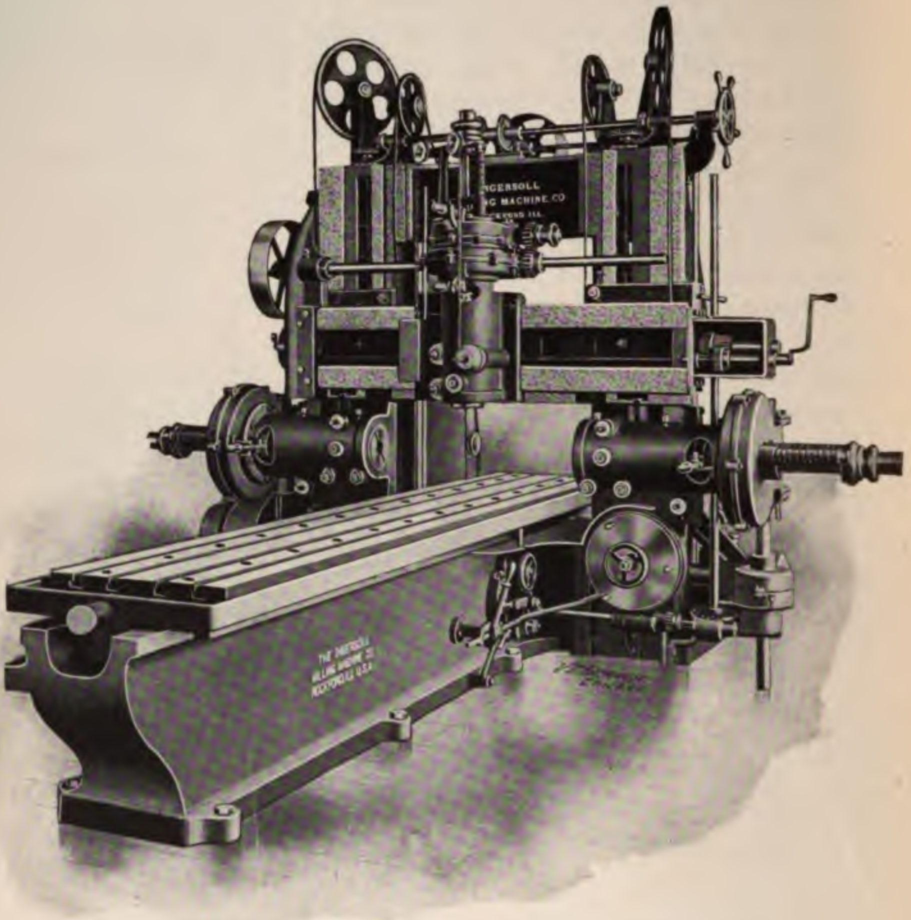


Fig. 204.

Another method of getting the clearance for the cutter is to place the top of the cutter blank as near the arbor as possible and then cut the desired shape. If the cutter is set in the arbor so that it projects from the surface it will have the necessary clearance as shown in Fig. 204. A represents the position of the blank while being cut and B the cutter in position for cutting; the dotted line showing the circle through which the cutting edge travels, the amount of clearance is apparent.



36" x 36" THREE HEAD MILLING MACHINE.
Ingersoll Milling Machine Co.

End Mills. This form of milling machine cutter (Fig. 205) is familiarly known as a **shank mill.** The term is used on account of the shank B which in small milling cutters fits into a collet. This collet in turn fits the hole in the spindle of milling machine. The collet referred to is used to save stock in making the cutters as otherwise it would be necessary to use steel large enough to make a shank of the size of hole in the spindle of the milling machine.

The cutter shown in Fig. 205 is what is termed a *left hand* mill; if the teeth run in the opposite direction, it is called a *right hand* mill.

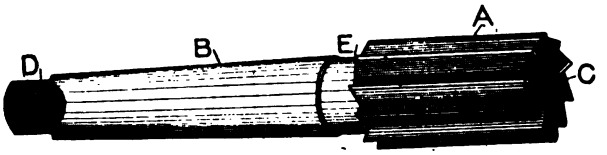


Fig. 205.

In making a shank (or end) mill of the form shown in Fig. 205 stock should be selected enough larger than the cutting end A to allow of turning off the decarbonized surface of the steel. After facing the ends to length, and turning the roughing chip, the end A may be run in the steady rest of the lathe and the center cut away — or recessed — as shown at C. The blank should be recentered and countersunk to furnish a center to use in turning the mill to size and shape. The object in cutting the center out as shown is to furnish a cavity for the angular cutter used in cutting the teeth on the end of the mill. Without this it would be impossible to grind satisfactorily.

After recentering the end C, the tenon D may be turned to size and milled to thickness, which should be a trifle ($\frac{1}{32}$ inch) less than the width of the center key slot in the collet. The taper at B should be turned enough larger than finish size to allow for grinding after the milling cutter is hardened. The cutter end A should be turned .010 inch larger than the required diameter. The portion E should be turned $\frac{1}{32}$ inch smaller than the large end of B or to dimensions if any are given on the drawings.

In order to insure teeth strong enough to resist the strain of cutting, an angular mill should be selected that will give the required shape. In Fig. 206 is shown a form of cutter tooth too weak for actual service; this tooth is the result of using an angular cutter with a cutting face forming an acute angle with the side. Fig. 207 shows a cutter whose teeth are strong, yet deep enough to be practical; these teeth were cut with an angular mill of less angle. Fig. 208 represents a cutter whose teeth were cut with the same cutter used for Fig. 206. The teeth were cut to the required depth first; this of course leaving them too thick at the cutting edges as shown in Fig. 209. After cutting the teeth as shown at A, Fig. 209, the index head was turned sufficiently to cut the teeth as shown at A, Fig. 208.

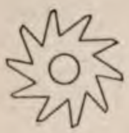


Fig. 206.

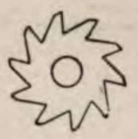


Fig. 207.

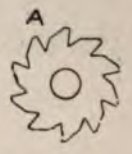


Fig. 208.

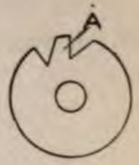


Fig. 209.

After cutting the teeth around the circumference of the mill, it should be placed in the collet and the collet put in the spindle hole in the spiral head in order to cut the teeth on the end.

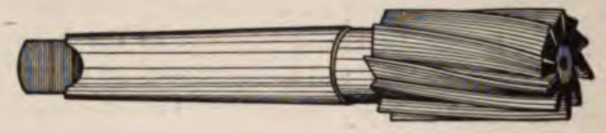


Fig. 210.

When cutting the teeth on the end of the mill, the spiral head is turned until the cutter is in a horizontal position. The angular cutter used should not have a very acute angle or the teeth will be weak. An 80° angular milling cutter will be satisfactory.

Spiral End Mills. It is sometimes advisable to cut the teeth of end mills spirally as shown in Fig. 210. As there is no support at the outer end of this form of mill it will be necessary to cut the teeth of a spiral that will have a tendency to force the mill into the collet rather than draw it out. Fig. 210 represents a left hand end mill cut with a right hand spiral.

End Mills with Center Cut. This form of End Mill is useful when it is necessary to cut into the work with the end of the mill, and then move along as in dies, cams, and grooves. The teeth being sharp on the outside, cut a path from the point of entrance. The coarser teeth allow a heavier cut, especially in cast iron. Fig. 211 shows two views of an end mill with center cut.

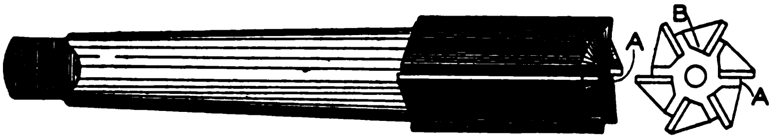


Fig. 211.

After cutting the teeth on the end with an angular cutter, a thin straight faced cutter of small diameter should be run through close to the face of the cutter tooth making a cut as shown at A; this cut should be of sufficient depth to permit of backing off the inner edge of the tool as shown at B. This clearance allows the mill to cut away the slight projection left in the center of mill when it is fed into a piece of work. Such a projection is shown at A in Fig. 212.

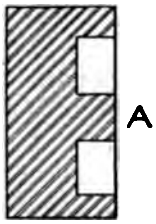


Fig. 212.

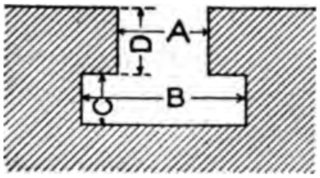


Fig. 213.

T-Slot Cutters. In cutting T slots in various parts of machines, such as milling machine carriages, etc., it is necessary to use a form of shank mill known as a T-Slot Cutter. Fig. 213 shows the ordinary form of T-slot; while Fig. 214 shows the cutter. A portion of the stock below the teeth is cut away as shown at A A in the sectional view Fig. 215. This is necessary in order to back off the teeth on the sides of the cutter for clearance, and to do away as far as possible with unnecessary friction when the cutter is working.

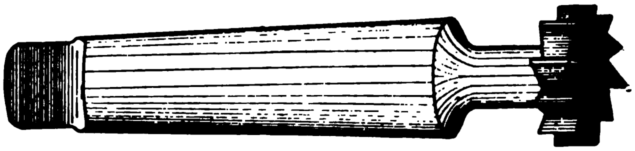


Fig. 214.

T-slot cutters are usually made $\frac{1}{32}$ inch larger in diameter than the size designated on the cutting portion to allow for sharpening; that is, a mill intended for cutting a slot $\frac{1}{2}$ inch wide is made $\frac{1}{2} + \frac{1}{32}$ or $\frac{17}{32}$ inch diameter, unless intended for cutting a slot to given dimensions.

It is advisable to harden mills of this description the entire length of the neck, especially if the neck is of small diameter; otherwise they will be very likely to spring when in use. After hardening, the neck should be drawn to a blue color, while the cutting part should be drawn to a straw color.

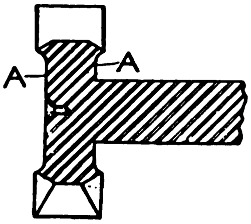


Fig. 215.

When grinding end mills, the shank in all cases should be ground first to fit the collet or holder, allowing it to enter *far enough* to key out readily, yet not enough to allow the shoulder above the tenon to strike the shoulder in the collet.

After grinding the teeth for clearance on the diameter, the teeth on the end should be ground. Most universal and cutter grinders are provided with a fixture for holding the mill by the shank while grinding these teeth; such a fixture is shown in Fig. 216.

Face Milling Cutters. This form of cutter is used in milling surfaces too large to be cut with the ordinary form of milling cutter held on an arbor passing over the work. As the full diameter of the face of the cutter may be used, it may have less than one half the size that would be necessary for a side milling cutter. A side milling cutter must be double the diameter of the surface to be cut plus the diameter of the collar on the arbor. For instance if a surface as A, Fig. 217, were to be milled, it would be necessary to use a cutter somewhat larger in diameter than twice the height of the surface plus the diameter of collar B. Whereas if a *face* milling cutter of the form shown in Fig. 218 were used the diameter need not be much greater than the height of the face of the piece of work being milled.

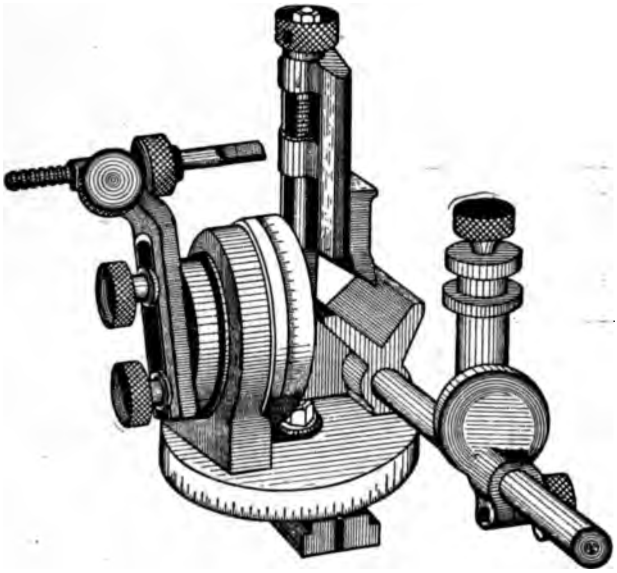


Fig. 216.

Generally speaking, cutters of this description are necessarily of a diameter that makes it advisable to use inserted teeth as shown in Fig. 218. The body may be made of cast iron, having a taper hole and key way, and held in place on the arbor by a screw.

The teeth may be made of tool steel and hardened, or of self-hardening steel if the cutter is to be subjected to rough usage. In either case they may be fitted to the slots by grinding on a surface grinder, and held in place by taper bushings and screws as explained under "Milling Cutters with Inserted Teeth." The construction of the body may be readily understood from the sectional view given in Fig. 219. The letters A, B, and C represent the diameter of cutter, width of face, and number of taper of the hole respectively, while D represents the key way.

The following table gives the dimensions of Face Milling Cutters of different diameters.

FACE MILLING CUTTERS.

A	B	C
5⅛"	2 "	No. 10 Brown & Sharpe Taper.
6⅛"	2 "	" 12 " " " "
7⅛"	2 "	" 12 " " " "
8⅛"	2⅜"	" 12 " " " "
9⅛"	2⅝"	" 12 " " " "

After boring and reaming the taper hole, the body of the cutter may be placed on a taper mandrel fitting the hole, and the ends and circumference finished to size. It should then be placed in the vise on the shaper or planer at the proper angle and the spline slot cut of an equal depth at each end of the taper hole. After removing the burrs it should be placed between the centers on the milling machine, and the slots cut for the teeth.

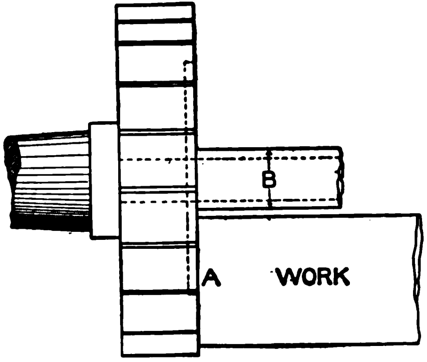


Fig. 217.

When the teeth are firmly secured in their proper places, they may be ground for clearance; the same general instructions given for grinding other forms of milling machine apply to this form.

Arbors For Face Milling Cutters. In. Fig. 220 is shown an arbor to be used in connection with *face* milling cutters. The shank A fits the hole in the spindle of the milling machine. B is the body which fits the taper hole in the cutter; this portion of the arbor has a spline which fits a spline slot in the cutter. A screw C enters the body of the arbor and is used in holding the cutter on the arbor. D is a nut used to force the cutter off the arbor when it is necessary.

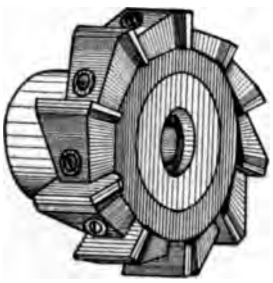


Fig. 218.

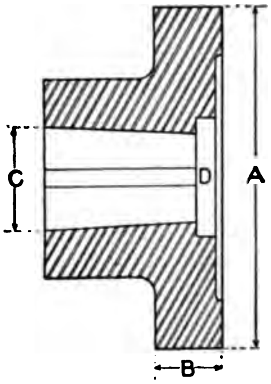


Fig. 219.

Stock used in making an arbor for a face milling cutter should be strong and stiff, and on this account tool steel is generally used. After squaring the end and roughing out the circumference, one end should be run in the steady rest and the screw hole in the end drilled and tapped, after which it should be countersunk at the end to furnish a center for use in turning and finishing. The tenon should now be turned to size and milled to thickness. If necessary to harden the end of the tenon it should be done before finish turning the arbor to prevent springing when heating. After turning the taper to fit the hole in the milling

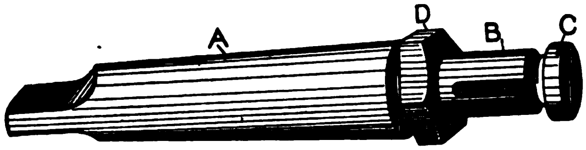


Fig. 220.

Sharp corners should be avoided wherever possible, and all handles or similar devices should fit the hand. If not, the amount of work done will not be the maximum, as the operator cannot do as much work with a jig which tires the hand and wrist.

As already stated the accuracy with which a jig should be constructed depends entirely on the nature of the work to be done, yet it should be borne in mind that any inaccuracy must of necessity be duplicated in the work.

EXAMPLES OF JIGS.

A few designs of jigs will now be considered to show the general requirements and the methods of construction.

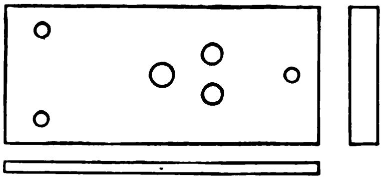


Fig. 222.

The slab jig, shown in Fig. 222, is the simplest form in use; it consists of a piece of flat stock of suitable thickness and of the same general outline of the piece of work to be drilled. The work may be clamped to the jig by means of U clamps, or parallel jaw clamps. If the jig is made of machinery steel the walls of the holes may be case-hardened by heating the jig red hot and sprinkling powdered cyanide of potassium around the hole, reheating in the fire and plunging in water; it should be worked back and forth in the bath so that the water will circulate through the holes. While this form of jig answers very well where but a few pieces are to be drilled, it is not suitable for permanent equipment on account of the wear of the holes. To overcome this, the holes may be made sufficiently large to receive hardened bushings having holes the size of the drill to be used. Fig. 223 shows this construction.

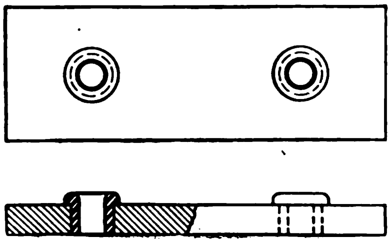


Fig. 223.

When holes are to be drilled at certain distances from one or or between the work and the stops, or locating points, throw the work out of true. As a result the holes will be at a wrong angle to the working surface, or they will be improperly located. Either condition would make the pieces unfit for use on most work, consequently bearing surfaces (wherever possible) should be cut away leaving several small seating surfaces, rather than one large one. A, Fig. 221, shows a piece of work resting on its entire seating surface; while B shows a surface cut away to leave six bearing points. If the seating surface is to be cut away as described, the raised portions should be so located that the article cannot be sprung by the action of the cutting tools or from any pressure that may be applied by any fastening device; otherwise the work will be thrown out of true as badly as though chips were lodged between the work and the seating.

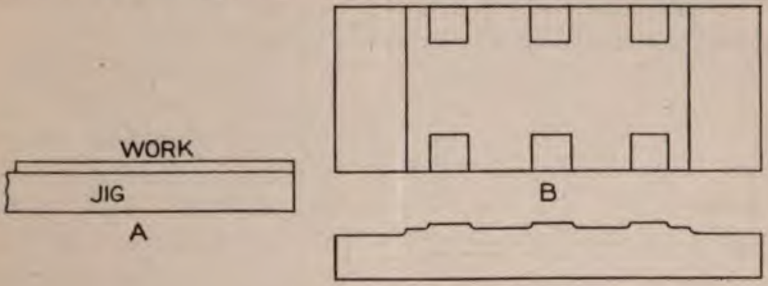


Fig. 221.

It is advisable, whenever possible, to divide a long, locating bearing into several short surfaces, thus decreasing the chance of holes becoming inaccurately located. When making jigs for pieces that are likely to have burrs at any given point, it is well to cut a depression in the seating or locating surfaces for the burr to set in, thus preventing the work being incorrectly located.

Seating surfaces should be made smooth so that chips and dirt may not stick to them, but they should not be polished nor finished as this would necessitate unnecessary cost and might cause the surface to get out of true.

A jig must be handled by the workman, and a clumsy jig cannot be handled as readily as one designed so that the workman can use it to advantage.

piece used having the holes properly located; this piece may be placed in the jig and by means of drills the holes are transferred to the jig. If the bushings are to be used the holes may be enlarged by a counterbore having a pilot which fits the drilled hole and a body of the desired size of the bushing. While this method is cheap and good enough for certain classes of work, it is not advisable to use it for a very accurate job.

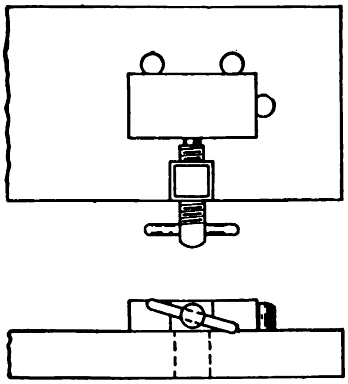


Fig. 226.

Another inexpensive method which insures *fair* results is to drill the holes as described above, then run a drill or reamer a trifle larger than the holes in the templet through the holes in the jig. Now place the templet in position and by means of a counterbore having a pilot which fits the hole in the templet counterbore the jig to the templet as shown in Fig. 228. Better results will be obtained if the ends of the teeth of the counterbore are made of the shape shown in Fig. 229, especially if the drilled hole should have run from its proper location.

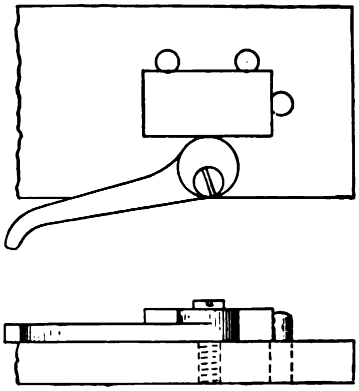


Fig. 227.

A third method is used when the bushing holes must be located by measurement, or when there is no templet or model piece. By means of a surface gauge having the point of the needle set at the proper height from a scale attached to an angle iron, as shown in Fig. 230, scratch a dimension line on the surface which has been colored with blue vitriol. The needle is first set to the height of the locating rib. The scale attached to the angle iron is adjusted so that the needle is at the exact height of one of the inch lines if possible, if not, at one of the half of quarter inch lines. The needle may then be raised to locate the center of the first hole and a line scratched while the jig is on edge. The centers of the other holes may now be laid off on this plane, after which the jig may be turned one quarter way around to locate the hole from the other measurements. Where the lines intersect prick punch the surface of the jig. For this work *do not* use the center punch made for centering work to be turned in the lathe. Use the prick punch which should be much lighter than the ordinary center punch; Fig. 231 shows the two punches. The point of the prick punch should be ground in some form of grinder in which it may be held and revolved in order that the point may be perfectly round. If this is not done it will be impossible to get the point of the center indicator to run true when attempting to true the jig on the face plate of the lathe.

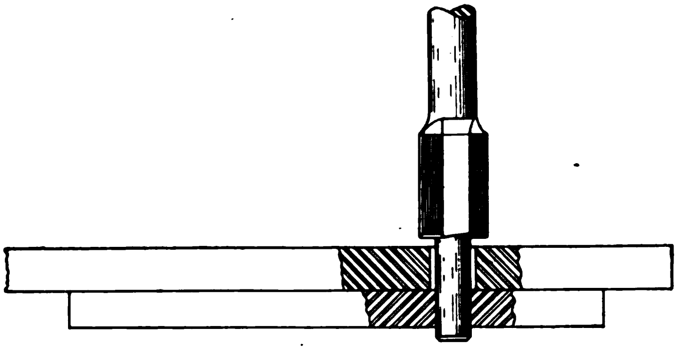


Fig. 228.

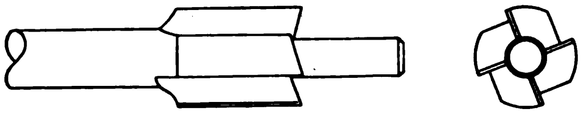


Fig. 229.

While the above method might be properly classed as an approximate measurement, an experienced workman can locate the bushings within a small limit of variation. More accurate work will result if the height gauge is used in laying off the dimension lines. The bottom surface of the extension is set to the height of the locating rib, as shown in Fig. 232; then by means of the vernier it may be raised to the exact height of the dimension desired, and the line scribed by means of the point of the extension.

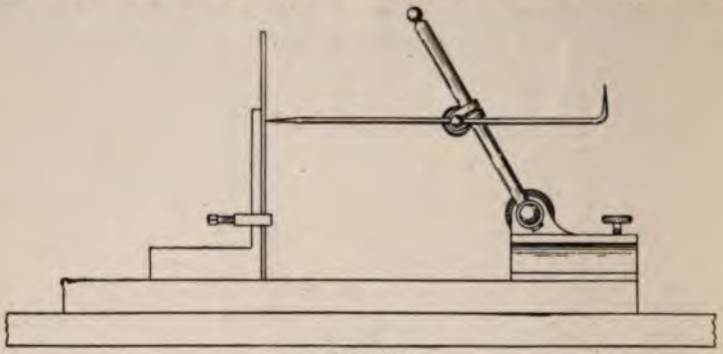


Fig. 230.

While this method insures greater accuracy in laying off dimension lines and is sufficiently accurate for most work, it is open to the objection that the tool maker may change the location of centers somewhat when prick punching.

When *precise* measurements are desired many tool makers determine the location of bushing holes by means of hardened discs or buttons. A very common size, Fig. 233, if $\frac{1}{2}$ inch diameter, $\frac{3}{16}$ inch thick and having $\frac{1}{4}$ inch hole. While it is not essential that the diameter be any particular size, it must be some fraction divisible by two without a remainder, as one half the size of the disc is considered in all computations. If the disc is .500

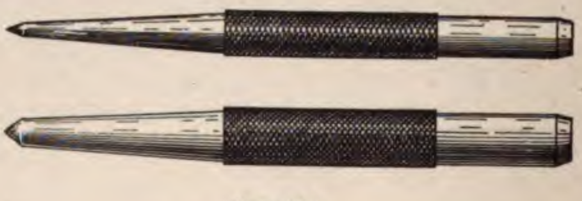


Fig. 231.

inch diameter, .250 inch is the decimal to be considered; but if the disc were $\frac{9}{16}$ (.5625) inch diameter it would be necessary to consider the decimal .28125 in all computations. In locating the disc most of the measurements are made with the vernier caliper, and as the tool is not graduated to read closer than .001 inch it would be impossible to consider the fractions of a thousandth of an inch; consequently discs .500 inch diameter are generally used.

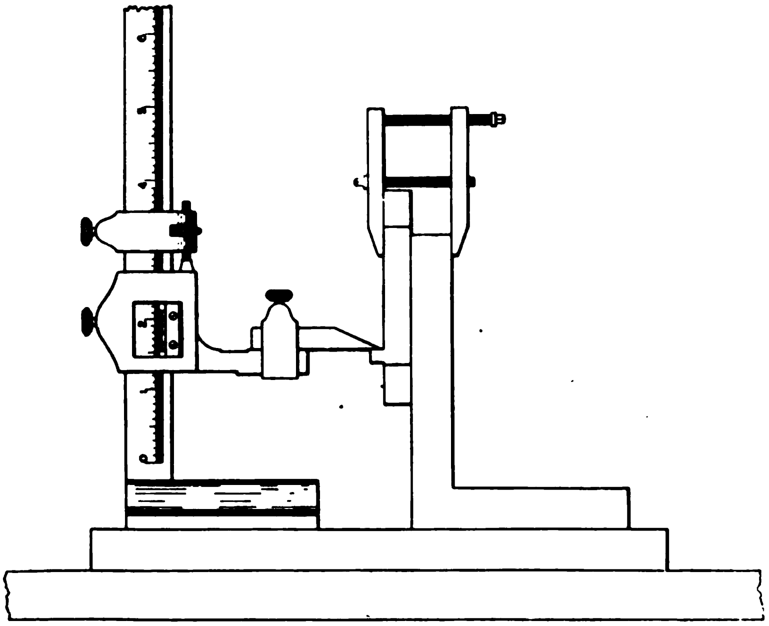


Fig. 232.

The locations of the different holes are laid off by means of the surface gauge, setting the needle to the scale fastened to an angle iron as already described. The holes are drilled and tapped for a screw somewhat smaller than the hole in the discs. The discs are now attached to the jig by means of screws. As the screws do not fill the holes in the discs, they may be moved until properly located. Fig. 234 shows a jig having the discs located in relation to the stops.

After properly locating a disc at each point where a bushing is desired, the jig may be fastened to the face plate of the lathe.

The jig must be so located on the face plate that one of the discs will run *perfectly* true. This may be determined by a test indicator operating on the outside of a button, as shown in Fig. 235. After locating so that the disc runs exactly true, the disc may be removed and the hole bored to the required size. The jig may now be moved to bring another disc to the proper location, after which it may be removed and the hole bored; this operation may be repeated until all the bushing holes are bored.

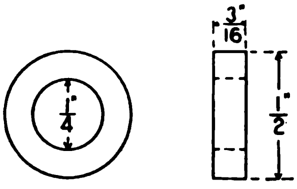


Fig. 233.

When jigs are made for permanent equipment, or if they are to be used constantly, it is well to provide some means of raising them from the drill press table to avoid inaccurate work occasioned by chips. When the jig is made of cast iron, the legs are sometimes cast solid with the jig as shown in Fig. 236. In order to grasp a jig handle in a manner that will not be tiresome to the wrist or hand, and allow sufficient room between the handle and the table of the drill press so that the fingers may not be cut by chips, the legs are made of a length that will raise the handle about $1\frac{1}{8}$ inches above the table. As cast-iron legs of this length would be too weak, it is customary to make the legs of tool steel hardening the ends that come in contact with the drill press table.

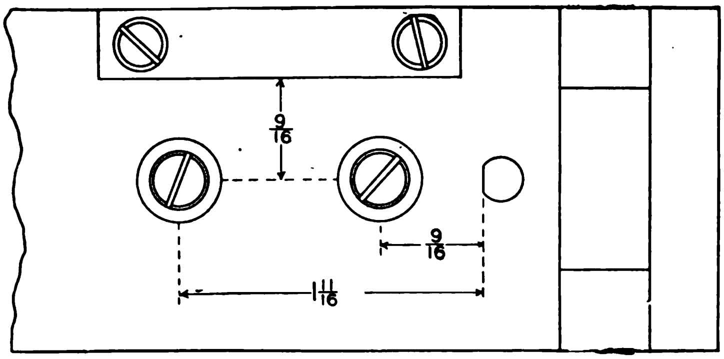
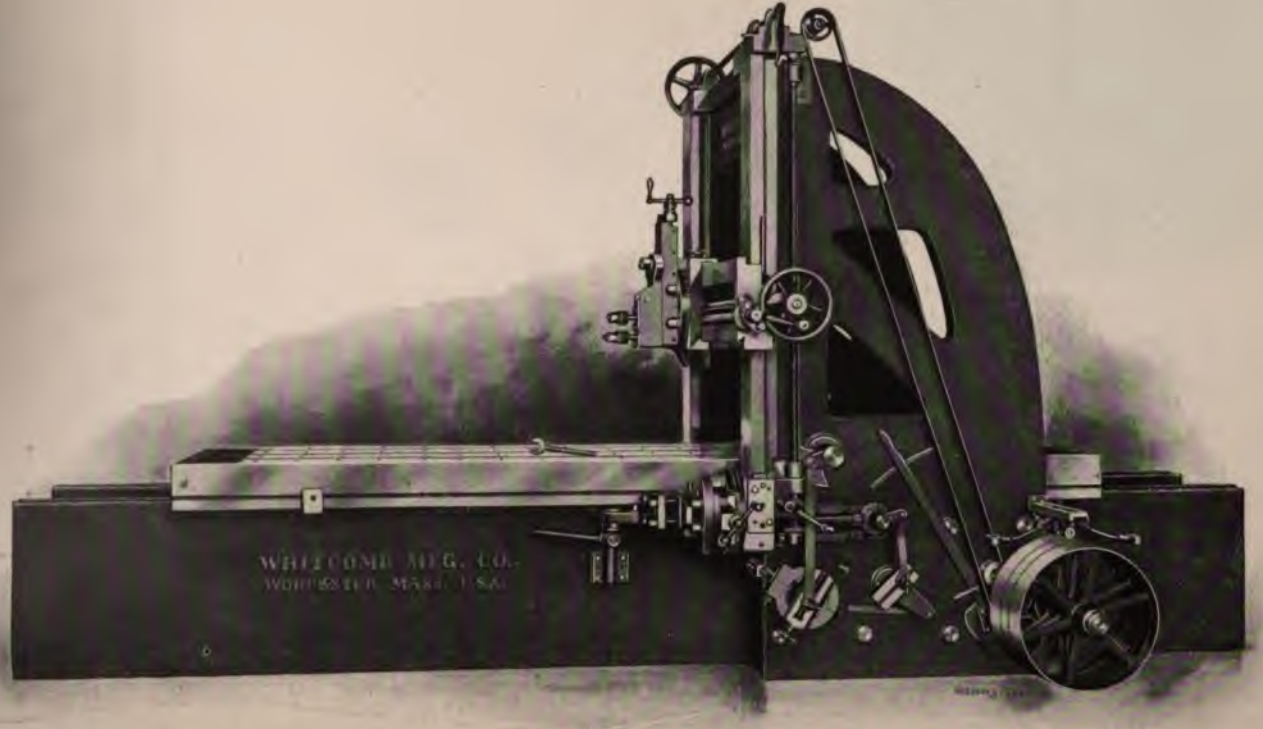


Fig. 234.

While the form of jig shown in Fig. 222 would give satisfaction on certain classes of work, the process of putting the work in,



36"x 36" x 10' PLANER.

Whitcomb Manufacturing Co.

and taking it out of the jig would be very slow, as it would be necessary to clamp the work securely to resist the pressure of the cutting tools.

In order that work may be handled rapidly during these operations, jigs are designed so that the work will rest on the base of the jig as shown in Fig. 237. A leaf or cover containing the bushings can be raised when putting the work in place and taking it out.

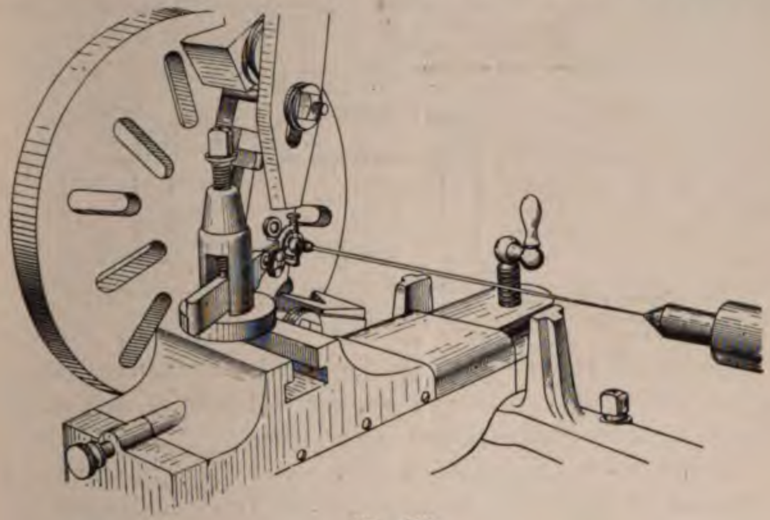


Fig. 235.

When the pieces to be drilled are of a uniform thickness the leaf may be made to rest on the piece. But should the pieces vary in thickness the leaf would not be parallel to the base; consequently the hole in the bushing would not be at right angles to the piece to be drilled. For this reason a little space is left between the top of the piece to be drilled and the bottom of the

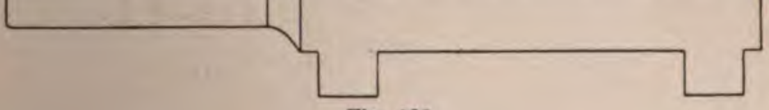


Fig. 236.

leaf, as shown in Fig. 238; a steady pin having a shoulder is located at the handle end of the jig. The upper end of pin may project into a hole in the leaf as shown thus relieving any strain on the joint of the jig occasioned by the action of the cutting tools.

When holes are to be drilled from opposite sides of a piece

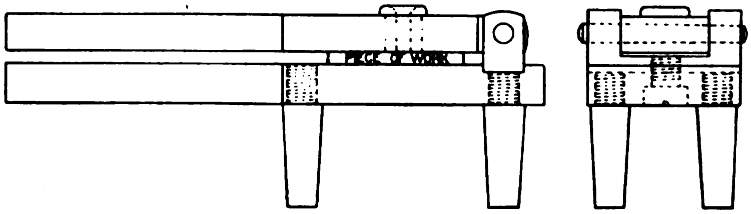


Fig. 237.

of work, as shown in Fig. 239, a jig may be constructed having legs on both upper and lower sides, but both sets of legs should be solid with the base as shown in Fig. 240.

If the two end holes in Fig. 239 are of the same size and it is necessary to use a drill press having but two spindles, the legs on each side should be of a length that would make it possible to

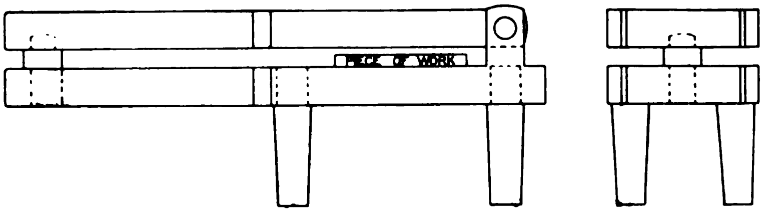


Fig. 328.

set the stops so that the drill would cut the required depth on each side. If a drill press having three or more spindles is to be used, the jig legs may be of a convenient length, as two drills of the same diameter can be used in two different spindles, each one to drill the required depth when the stop is set.

Drill jig legs are generally made of tool steel and are screwed into the base of the jig: the thread on the legs should be a good fit in the base. After screwing in place the ends of the legs should be machined to length by milling or planing; the legs may then be removed and the ends that come in contact with the drill press table hardened. The legs may now be polished (if that is allowable) and then screwed in place. The ends should now be ground to such a length that the surface where the work is seated will be of the correct height above the drill press table.

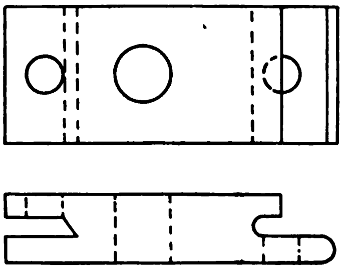


Fig. 239.

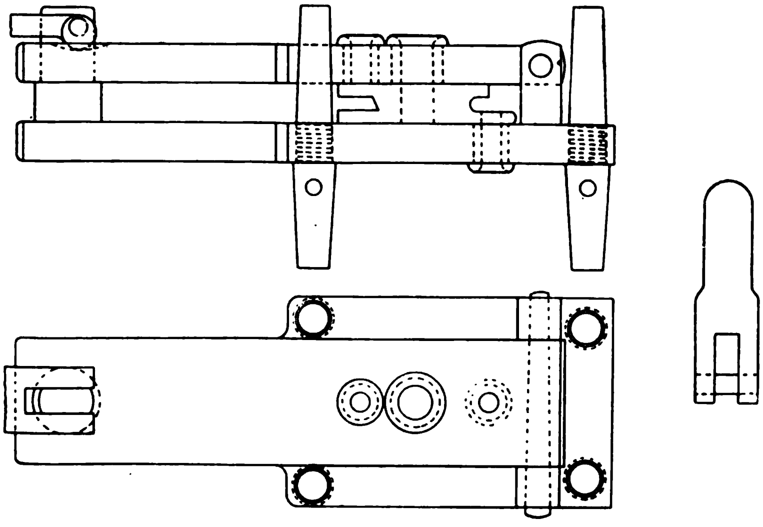


Fig. 240.

Grinding the ends of the legs can best be done in a surface grinder, or some form of universal grinder designed for surface grinding. After grinding, the ends of the legs may be lapped to remove any irregularity that may result from grinding. A very good lap may be made from a flat plate or block of cast iron. The surface to be used may be planed flat and smooth, then a series of grooves cut to form squares, as shown in Fig. 241. These grooves may be cut with a V-shaped tool and should be $\frac{1}{4}$ inch to $\frac{1}{64}$ inch to $\frac{1}{32}$ inch deep. The grooves catch the emery and feed it to the work being lapped. If the pressure is not equal one leg may be

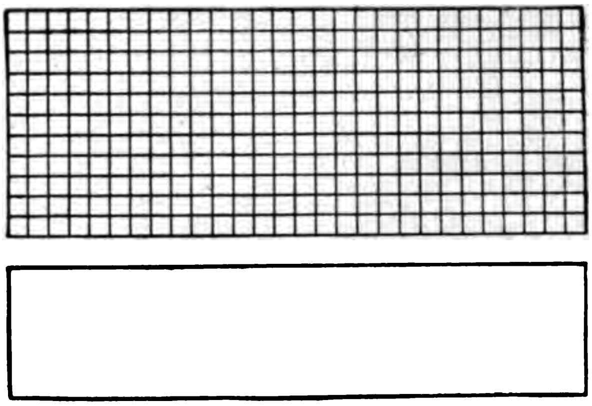
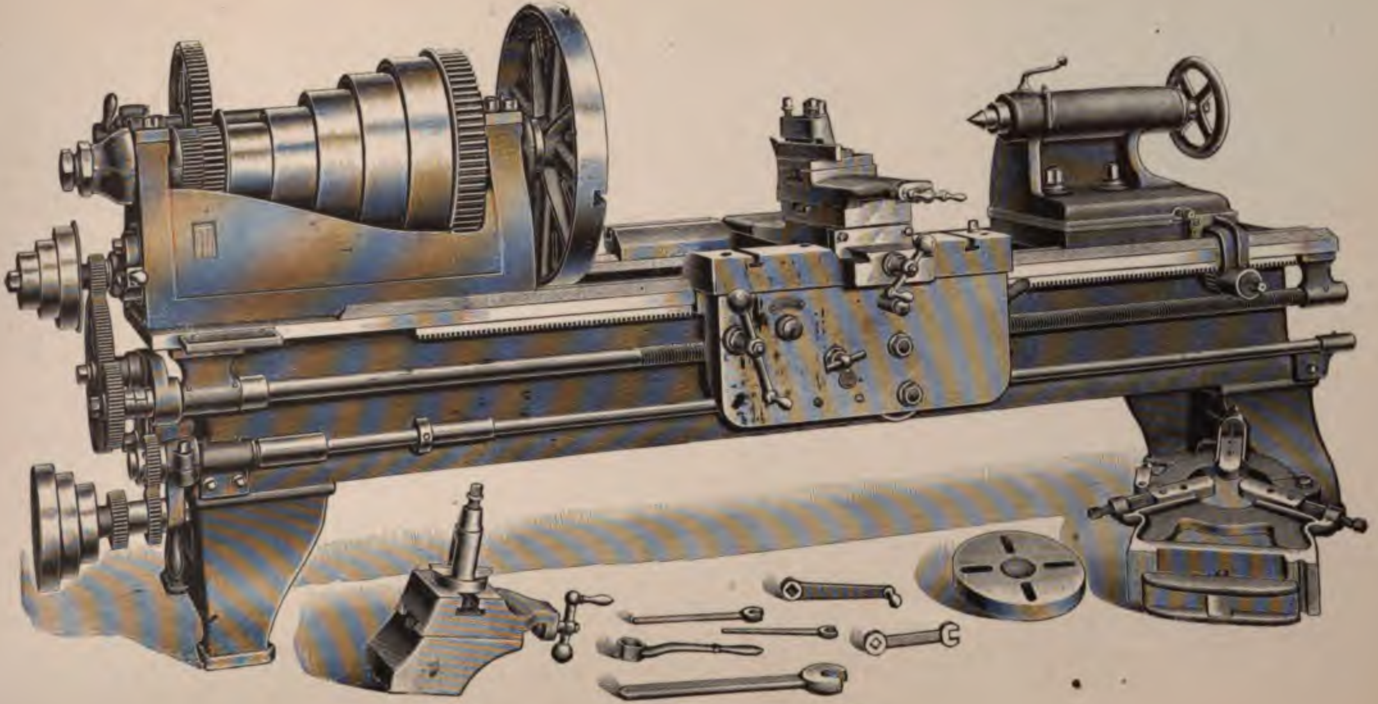


Fig. 241.

cut shorter than the other, or may be lapped out of true, causing the jig to rock.



24-INCH SWING ENGINE LATHE.

F. E. Reed Company.

TOOL MAKING.

PART III.

DRILL JIGS.

Fastening Devices. Various devices are used to fasten the leaf of a jig to hold the work in place or to clamp the leaf in position. The forms used depend upon the class of work being operated on.

If the leaf must be fastened solidly and the amount of time consumed is not of great importance, some form of screw clamp may be used. If, however, the work must be handled rapidly, the clamping device is generally operated by some form of a cam. However, a screw clamp may be designed to work quite rapidly.

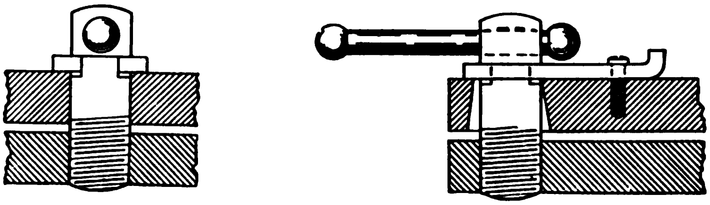


Fig. 242.

Fig. 242 shows a screw clamp which consists of a screw which has a hole drilled through it to receive a pin which is used as a lever to operate the screw. The screw is necked $\frac{1}{16}$ inch deep, the necking being $\frac{1}{8}$ inch wide; a flat washer is attached to the leaf of the jig by a small screw as shown. A slot of the width of the screw is cut in this washer in order to allow it to slide back and forth. In the end of the washer is a slot the width of the bottom of the necking in the screw. The other end of the washer is turned up as shown, in order to furnish a means of pushing back and forth. When the jig leaf is closed, the washer is pushed forward and the ends engage in the slot in the screw. One turn of the screw binds it very tightly. When the screw is given one turn to loosen it, the washer may be pushed back and the jig leaf raised.

If a quicker form of clamping is desired a cam may be used. The form represented in Fig. 240 is rapid and powerful.

Were it not necessary to use much power, but extreme rapidity of action is desired, a hinged cam lever of the design shown in Fig. 243 may be used. The cam lever is pivoted to the base of jig by means of a pin as shown. The lever passes into a slot in the leaf and the bearing surfaces on the under part of the head come in contact with the inclined surfaces at the end of the leaf.

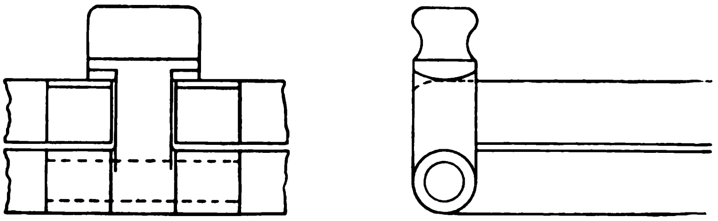


Fig. 243.

Bushings. Bushings of hardened tool steel are made for a permanent means of guiding the cutting tools. The hole in the bushing is made to fit the cutting tool that is to be guided. There are various forms of bushings; the plain straight form shown in Fig. 244 is sometimes used, but is objectionable because it may be pushed into the jig if the cutting tool is too large to pass through the hole.

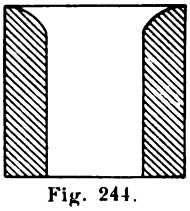


Fig. 244.

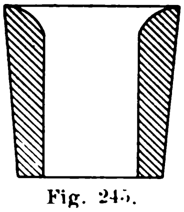


Fig. 245.

To overcome this tendency they are sometimes made **tapering** on the outside as shown in Fig. 245, but as this is an expensive form to make, and as it is an extremely difficult operation to bore the bushing hole in the jig, this form is not generally used for permanent bushings.

The most common form of bushing is straight with an enlarged portion or head. When no allowance is made for grinding on the outside it is commonly made of the form shown in Fig. 246. If the shoulder under the head is square, it is likely to crack at the sharp corner, or the head may be broken off when being forced in position. In order to avoid these difficulties a fillet is left under the head as shown in Fig. 247.

When it is essential that the location of the drilled hole or portion of the piece being machined in the jig be exact as to location, the tool must fit well in the bushing; and as the size and shape of the bushing is likely to change when hardening, it is advisable to leave enough stock to grind to size both inside and out. It is essential that the outside of the bushing be exactly concentric with the inside. After grinding and lapping the hole to size, the bushing may be placed on a mandrel which runs true and the outside ground to size. When machining a bushing which is to be ground on the outside it is necessary to neck in, under the head, as shown in Fig. 248, in order that the emery wheel may pass entirely over the part being ground and insure a straight surface. The under side of the head which rests on the upper surface of the jig should be ground in order that it may be true with the surface of the jig.

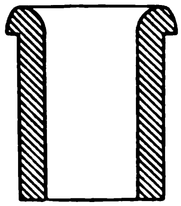


Fig. 246.

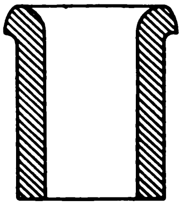


Fig. 247.

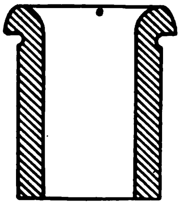


Fig. 248.

When grinding a bushing, a mandrel should be used which has been tested for truth. The mandrel should be straight or of very slight taper. If the taper is considerable, one end of the hole in the bushing, will not fit and the outside of the bushing will not be concentric with the hole. Consequently no matter how careful the tool maker might be in laying out his work and in boring the holes for the bushings the jig will not be accurate.

Size of Bushings. The outside diameter of a bushing is often determined by the design of the jig; for instance, two holes are often located so near each other that it is impossible to make the bushings much larger than the holes through them. Wherever possible the outside diameter should be made enough larger than the hole to leave a reasonably thick wall. A bushing with thin walls is likely to close in when being pressed to its seating; then again, if a cutting tool binds in a bushing with thin walls, the bushing becomes loose and turns in the jig.

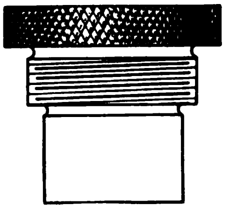


Fig. 249.

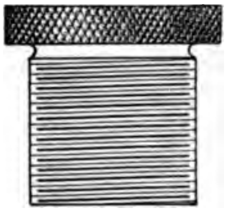


Fig. 250.

Removable Bushings. It is sometimes advisable to do two or more operations in the same jig. After drilling a hole it may be considered good practice to counterbore or tap it, or possibly it may be better to do the three operations while the work is seated in the jig. In such cases the bushing having a hole the size of the drill must be removed and one with a hole fitting the tool to be used inserted.

A very simple way of making a removable bushing consists in boring the hole in the jig large enough to receive a hardened bushing with a hole the size of the outside of the bushing to be used. If the hole in the large stationary bushing and the outside surface of the removable bushing are lapped smooth after grinding, they may be used for a long period before wearing enough to appreciably affect the location.

Tapered removable bushings are sometimes used; but on account of the expense of producing them and the fact that chips and dirt readily throw them out of their true locations, they are not very common.

Fig. 249 shows a form of removable bushing threaded on the outside to fit a threaded hole in the jig. If the thread on the outside of the bushing runs the entire length the process of screwing it in and out of the jig is necessarily very slow; consequently it is advisable to have but few threads. The balance of the length may be made to fit a bearing in the jig. If it is advisable to thread the entire length as shown in Fig. 250, the hole should be ground true with the thread to prevent change of shape in hardening. As it is not well to attempt to grind between the lands of the thread with the facilities in the ordinary machine shop, it is necessary to grind the hole true with the thread. This can be done satisfactorily by placing a piece of stock in a chuck on a lathe having a grinding attachment.

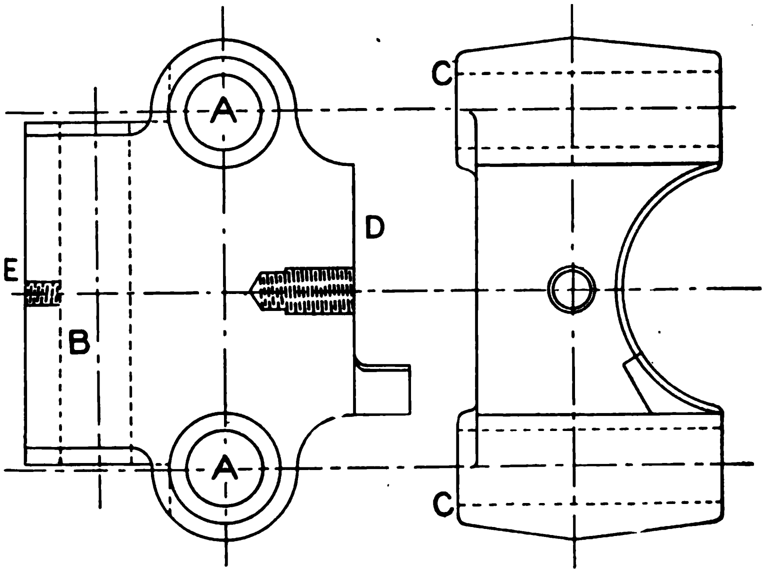


Fig. 251.

After drilling and boring the hole to tapping size, the thread may be chased so that the bushing is a good fit in the hole. It may then be screwed in and the hole ground to size.

If the piece of work is of a shape that makes it necessary to operate on all sides and the outline prevents the use of a clamp jig of the forms shown, a box jig must be used.

A Box Jig is made in the form of a box; the work is located in the jig by means of stops or locating points which differ according to the nature of the work. It is often advisable to design this form of jig so that all the holes in the work may be drilled at one setting; that is, if there are twenty holes in the piece, the jig is designed to allow drilling all the holes while the piece is in the jig. For other work it is advisable to make two or more jigs to drill the holes; this is the case when some part of the piece is to be machined after one or more holes are drilled but before drilling the others.

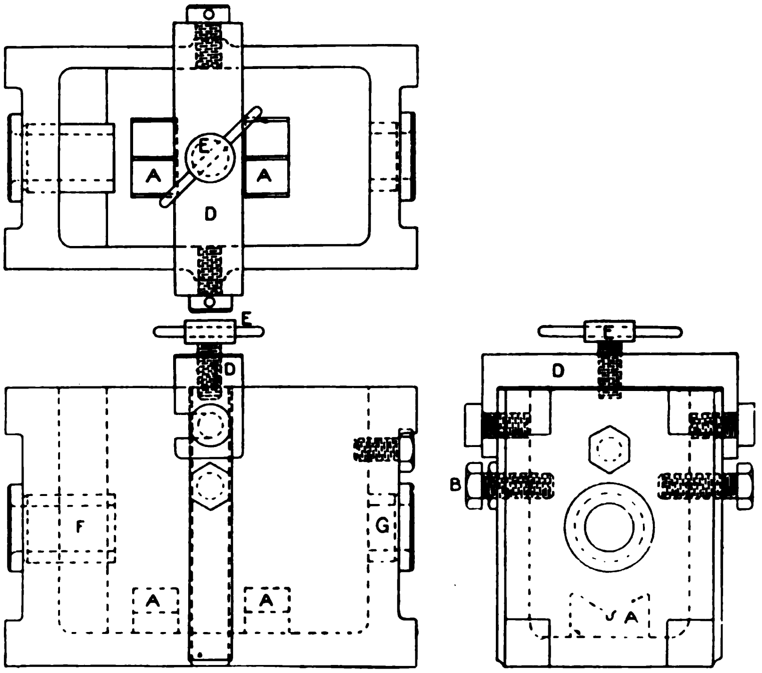


Fig. 252.

In Fig. 251 a piece of work is shown (three eighths size); through the piece it was necessary to drill three 1-inch holes as shown at A, A and B. As it was necessary to have the holes A A an *exact* distance from B it was found by experience that much better results could be obtained if the hole marked B was drilled and reamed in a jig, the piece taken out of the jig and the portions marked C and C milled in exact relation to the hole B and as nearly at right angles with the side of casting marked D as possible. After milling the portions C C, as described, the piece was placed in another jig locating it by the hole B and the surfaces C C; the holes A A were then drilled and reamed. In order to drill the hole B the jig shown in Fig. 252 was used.

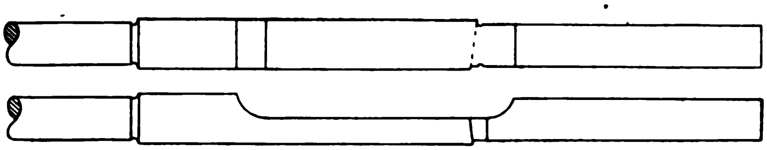


Fig. 253.

The piece was placed in the jig with the rounded surface E resting in two V blocks as shown at A. It was located by means of the fixed stop screw B and forced against A by the screw; it was held in position by the screw E which was located in the strap D. This strap was removed when putting a piece of work in the jig, or taking it out. As it was necessary to have the hole straight and true with the locating points, it was reamed with a single lip

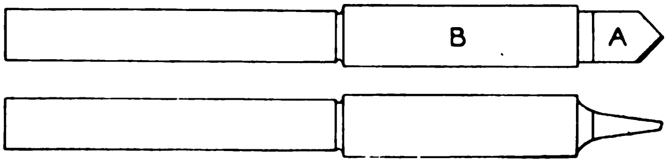


Fig. 254.

reamer having a pilot as shown in Fig. 253. The hole was drilled somewhat smaller than finish size ($\frac{1}{64}$ inch); the reamer was entered in the hole, the pilot fitting the bushing G. While the body of the reamer fits the bushing F, as previously explained, the single lip reamer acts on the same principles as a boring tool used in the engine lathe; the result being a hole straight and true. As it is necessary to have the hole in the upper bushing of the size of the body of the reamer, and as a drill $\frac{1}{64}$ inch smaller than this size must be used in drilling the hole, it was advisable, in order to properly start the drill, to use a transfer drill shown in Fig. 254, the cutting portion A of drill being the size of the drill to be used in drilling the hole, while B fits the hole in the bushing. By means of this drill a hole the size of the drill to be used was started in the casting perfectly true with the hole in the bushing yet somewhat smaller. When the hole had been drilled to a depth of $\frac{3}{16}$ or $\frac{1}{4}$ inch, the transfer drill was removed and a twist drill of the proper size used to finish the drilling. When the piece of work was taken from the jig the portions marked C C, Fig. 251, were milled as explained. The piece was then placed in another jig, a pin which fits the reamed hole passed through the locating bushings and through the hole; by this means it was located to properly drill the other two holes. The second jig so closely resembles the first it is unnecessary to illustrate it.

PUNCH AND DIE WORK.

THE DIE.

A die used for punching a blank from a sheet of metal is termed a blanking die, and is generally considered as belonging to one of three classes: plain (or simple) die, gang die or compound die.

A set of blanking dies consists of a male die or *punch* and a female die or *die block.* The die block is that part of the die which has a hole of the same outline as the desired blank; the male die, or punch, is of a shape that fits the impression, or hole, of the die block.

When punching work on a punching press, the stock is placed on the die and the punch forced through it into the die; this drives a piece of stock of the same outline as the hole down into the die block. Now as the punch is forced through, the metal in the sheet closes on the punch and is raised by it. In order to prevent this the die block is provided with a *stripper plate* (or stripper). The stripper is fastened to the die or to a shoe holding the die at a height that allows the metal to be punched to pass freely between it and the die. The stripper must be strong enough to force the stock from the punch without springing, especially if the punch is slender and the stock thick, because under these conditions the punch would be sprung or broken.

In order to guide the stock over the die and leave the proper amount of margin or scrap at the edge of the sheet, a *guide* is furnished. The guide is usually made of stock sufficiently thick to bring the stripper the proper height above the face of the die.

A *gauge pin* (or stop) is usually provided; this pin is located so that the proper amount of scrap is left.

In Fig. 255, A is the die block, B the hole through the die block of the shape of the piece to be punched, C the stripper, D the guide and E the gauge pin or stop.

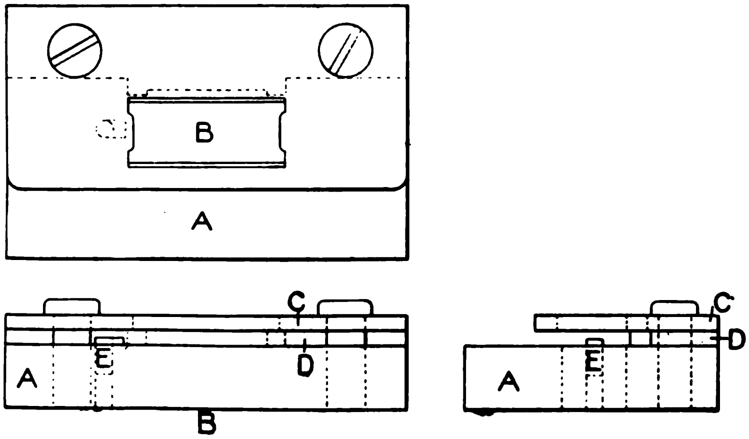


Fig. 255.

Dies are held in position on the punching press bed by various methods, the most common of which is by means of the forms of hold-fast shown in Figs. 256 and 257. These die holders are known by various names, such as chair, bolster, chuck and die holder. Large dies are clamped to the bed of the press.

Dies are usually beveled on the edges that come in contact with the die holder to prevent their rising from the seat. The angle given to the edges varies according to the ideas of the designer. An angle of 10° from the vertical gives satisfaction, although some mechanics insist on an angle of 15° or even 20°.

Fig. 258 shows a die, whose edges are at an angle of 10°, in a die holder; the die being held in place by set screws. It is generally considered advisable to place a gib between the set screws and die as shown. Sometimes the gib is omitted, the set screws bearing directly on the edge of the die. Some tool makers prefer a die holder without set screws, the die being held in place by the gib which is made wedge-shaped and is driven to place, thus securely holding the die.

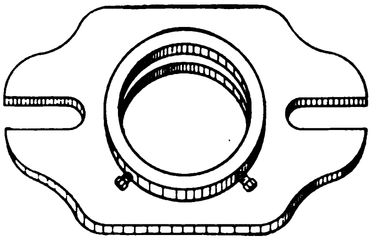


Fig. 256.

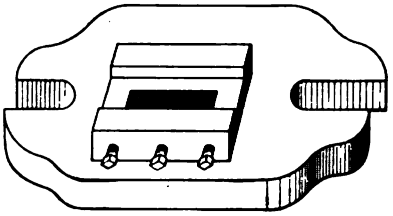


Fig. 257.

Fig. 259 shows a method of holding dies which allows the die to be easily set in position when rigging up. The die may be placed on the seating of the die holder and brought to the proper location; the set screws may then be brought against the edge of the die, or against strips of steel which may be placed between the edges of the die and the set screws.

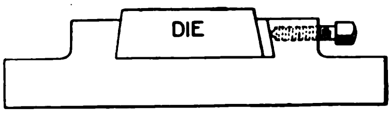
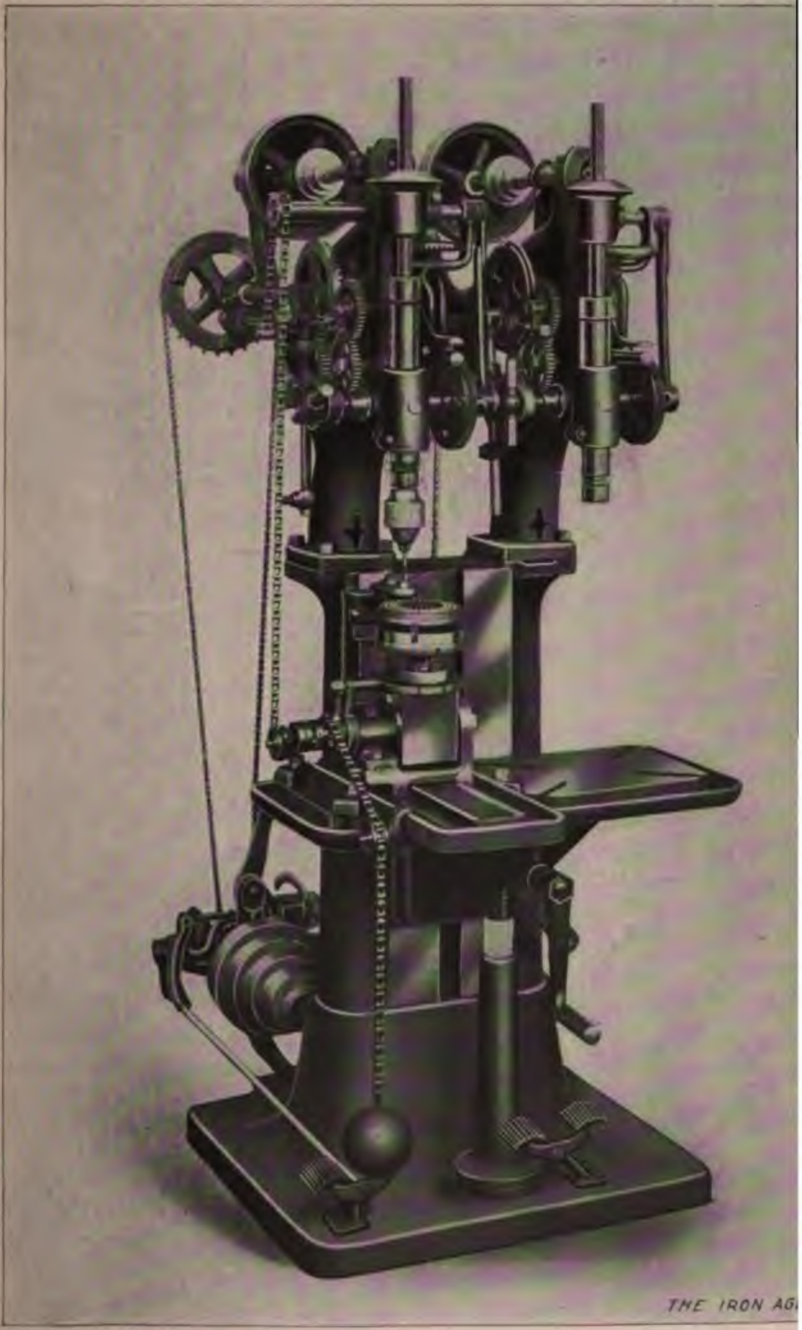


Fig. 258.

When making several dies of equal width and thickness a good method is to plane the two sides of a bar to remove the outer surface, then bevel the edges to the required angle. Pieces may then be cut off to any required length as wanted.

The upper surface of the die may be finished smooth by planing with a smoothing tool; it may be ground in a surface grinder, or it may be finished with a file. It is necessary to have the surface smooth in order to lay out the correct shape of hole, as it cannot be laid out correctly or distinctly on a roughly machined surface.

The face, or upper surface of the die is now covered with blue vitriol solution and the outline of the piece to be punched laid out. A die should be laid out in such a manner that the



TWO-SPINDLE AUTOMATIC DRILL.
B. F. Barnes Co.

stock to be punched may be readily fed to the die. The *grain* of the stock should run in the proper direction if the product is to be a tempered spring or any article where the grain of the stock must be considered.

After the die has been carefully laid out from a templet, or drawing, all round corners should be drilled with a drill of the proper size, and reamed from the back side of the die with a taper reamer to give the desired clearance; the balance of the stock is removed by drilling, as shown in Fig. 260. The method of removing the center, or core, depends on the custom practiced by the individual die maker; one may drill the holes so that they break into one another. When this method is adopted it is advisable to use a straightway (straight fluted) drill. Another will drill small holes and use a counterbore to enlarge to size; the counterbored holes breaking into each other.

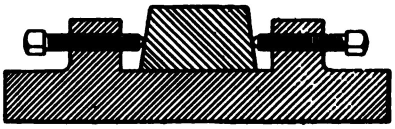


Fig. 259.

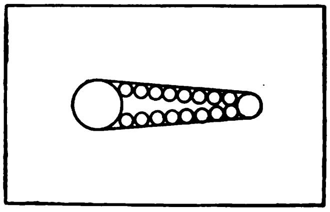


Fig. 260.

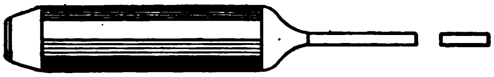


Fig. 261.

Usually the holes are drilled with at least $\frac{1}{64}$ inch to $\frac{1}{32}$ inch between them, and then the intervening stock is cut out with a flat-ended "hand broach." Fig. 261 shows a tool of this description.

Generally speaking, the last mentioned method is the safest and quickest. After removing the center, the die may be placed in a die milling machine or a die sinking machine, and by using a milling cutter of the proper taper, the desired angle of clearance may be given; the amount of clearance varies with the nature of the work to be done.

When a die is milled on a die milling machine of the form shown in Fig. 262, the cutter spindle is underneath the die, the face of which is uppermost, consequently the milling cutter can be made largest at the shank end of cutting part, the required taper being given as shown in Fig. 263. If the outline of the hole is milled on a die sinking machine, it is necessary to use a cutter of the shape shown in Fig. 264 in order that the face of the die having the lines will be uppermost. After working the impression as near to shape as possible by milling, it can be finished by filing. In order to give the die the proper clearance the walls may be gauged with a bevel gauge of the form shown in Fig. 8. As the amount of clearance differs in various shops, and on different classes of work, no stated amount can be given for all cases; the amount varies from ¼° to 3°. The latter is excessive and is seldom given unless it is necessary that the piece punched drop from the die each time.

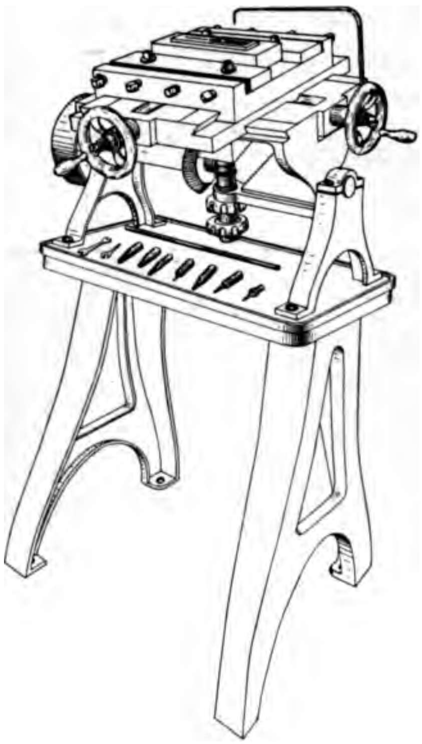


Fig. 262.

If the die is milled as described above it will be necessary to work all corners to shape with a file. If a universal milling machine having a slotting attachment is used, the corners can be properly shaped and the necessary clearance given by using suitably shpaed cutting tools, and turning the fixture to the proper angle.

Fig. 265 shows a slotting fixture attached to a universal milling machine, while Fig. 266 shows a fixture known as a die shaper which is also attached to a milling machine.

Die blocks have their cutting edges beveled in order that the blank may be cut from the stock by a shearing cut. *Shear* is given the face of the die to reduce the power necessary to cut the blank from the stock; thus enabling a press to punch a blank from thicker stock. It also reduces the strain on the punch and die.

The face of the *die* is sheared when the blank, or piece forced through, is the product to be saved. But if the piece surrounding the blank is to be saved, and the blank is of no use, the face of the die is left perfectly flat and the end of the *punch* is sheared.

Fig. 263.

The cutting face of the die may be sheared by milling or planing to the desired angle which depends on the thickness of the stock to be punched and also the power of the press. A common method of shearing a die is shown in Fig. 267, which shows a section of a die used for punching a heavy spring. The end of the *punch* is left flat. The punching commencing at the center A, is continued with a gradual shearing cut as the punch descends until it reaches the ends BB, of the opening. The blank punched will be straight while the stock will bend somewhat unless it is quite stiff, in which case it springs back to shape when the pressure is removed.

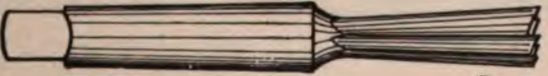


Fig. 264.

When the punching requires an amount of power in excess of the capacity of the press, as in the case of the forging shown in Fig. 268, it is necessary to trim the flash occasioned by the process of drop forging, and at the same time punch the end to shape as shown in Fig. 269. It is obvious that the material removed is of no value as a product, and as it is necessary to use a light press, the die may be given a shear as shown in Fig. 270; thus making it possible to do the punching on a press whose capacity is not equal to the job if the die had been sheared as shown in Fig. 267.

In order to facilitate the operation of grinding the face of a die, it is frequently made with a raised boss around the hole as shown in Fig. 271.

Sectional Dies. In order to make it easier to work dies to shape, they are sometimes made in two or more pieces; these are fastened together when in use. In the case of a plain die of the form shown in Fig. 272, the die is made in two pieces which are held in their relative positions by the dowel pin at each end as shown at A and B. When in the die holder they are held together in such a manner that they cannot spread. Dies of this form should have the surfaces that go together finished true; the pieces should then be clamped together and the dowel-pin holes drilled and reamed. They should then be taken apart and any burrs caused by drilling and reaming removed. The pins should now be inserted and the top and bottom of the die planed. The outlines of the piece to be punched may now be laid out and the round hole at one end drilled; after which it should be reamed from the back with a taper reamer to give clearance. The die may now be taken apart, and the opening cut out on the planer or shaper; the sections of the die being held at the proper angle to give the desired amount of clearance. After placing the two pieces together the opening may be finished with a file and scraper to the templet.

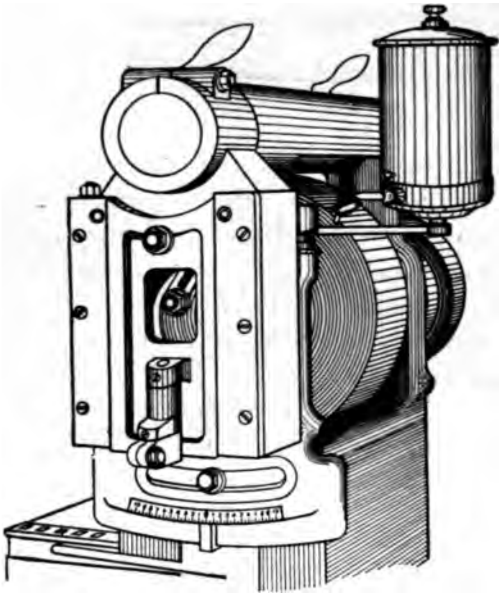


Fig. 265.

To hold the die together securely it is necessary to use a die holder of the form shown in Fig. 273. The die is represented in place in the holder which is held in the bolster which is in turn attached to the bed of the press. When the die is finished to the templet and the proper clearance given, make sure that the walls of the opening are straight (not crowning), although it is not always considered advisable to carry the clearance to the edge, as the size of the opening would then increase every time the die was sharpened. In such cases the clearance extends from the bottom to within a short distance (about $\frac{1}{8}$ inch) of the cutting surface as shown in the sectional view, Fig. 274. In this figure the clearance is exaggerated in order to illustrate the idea.

The walls of the upper part of the opening are at right angles to the base of the die, but they must be straight, that is, not crowning; because if the opening is wide enough to allow the punch to pass through the crowned part, the stock, if thin, would be likely to leave the blank with ragged edges which would extend up on the sides of the punch and have a tendency to burst the die.

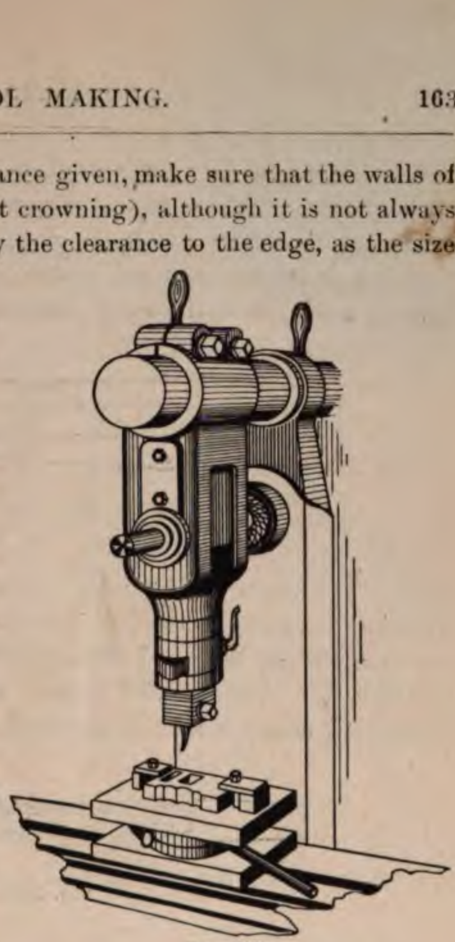


Fig. 266.

Before hardening, the stripper and guide-screw holes should

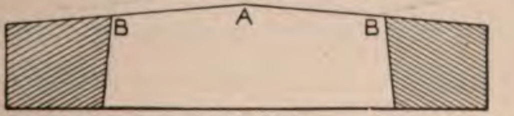


Fig. 267.

be drilled and tapped and the hole drilled for the gauge pin, or stop. If the name of the part to be punched, or the shelf number of the die are to be stamped it may be done now. After all screw holes, stop-pin holes, etc. are filled with fire clay mixed with water to the consistency of dough, the die is ready for hardening. Extreme care should be exercised when heating a die for hardening: it should be no hotter than is necessary to accomplish the desired result, and the heat should be uniform throughout; the corners must be no hotter than the middle of the piece and the outside surface must be of the same temperature as the interior of the steel. The water in the bath should be slightly warmed to prevent any tendency to crack. The die should be lowered into the bath and swung back and forth gently so that the bath may pass through the opening, and harden the walls. As soon as the "singing" ceases it may be removed and plunged into a tank of oil and allowed to remain until cold. It may then be brightened and the temper drawn. If more than a few minutes is to intervene between the time the die becomes cold, and commencing to draw the temper, it should be held over a fire or placed where it can be heated to remove the internal strains which have a tendency to crack the piece.

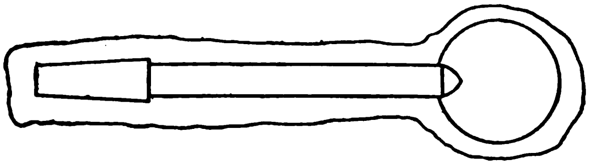


Fig. 268.

Fig. 269.

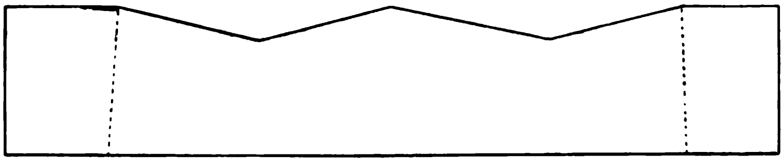


Fig. 270.

A very common method of drawing the temper of dies and similar pieces, is to heat a piece of iron to a red heat and place the hardened piece on it leaving the face of the piece uppermost. Experience has taught the writer, however, that this method of treatment is too harsh for hardened steel, especially if the job is in the hands of one not thoroughly experienced. One side of the piece is subjected to an intense heat while the opposite side is exposed to the cooling effects of the air. If an open fire is used a plate may be set on the fire, and the die placed on the plate before it is hot; now the temperature of the plate may be raised gradually, turning the die occasionally. In this manner the temper may be drawn to the desired degree with safety. When such a fire is not available two plates may be used, one heating while the other is in use. The first one should not be very hot, the next somewhat hotter, and so on until the die is drawn to the desired color.

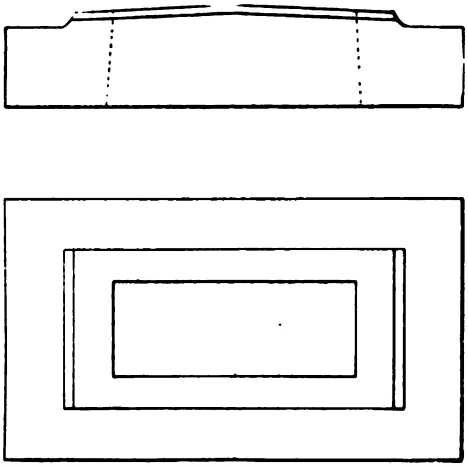


Fig. 271.

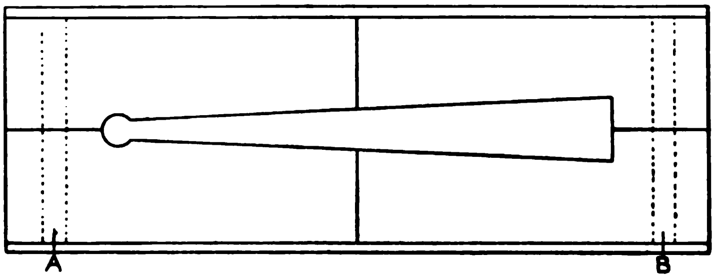


Fig. 272.

When a die of such a shape that is likely to give trouble, is to be hardened much more satisfactory results will follow if the "Pack Hardening" process is used. Run the dies from 1 to 5 hours in the fire after they are red hot, then dip in raw linseed oil.

THE PUNCH.

The punch is used to force the metal through the die thus producing pieces of the desired shape.

In the case of small plain dies the punch is generally made of the form shown in Fig. 275. The end A is of the same outline as the opening in the die, the shoulder B which bears against the shoulder of the punch holder takes the thrust when the punch is working. The shank fits the hole in the punch holder, or in the ram of the press.

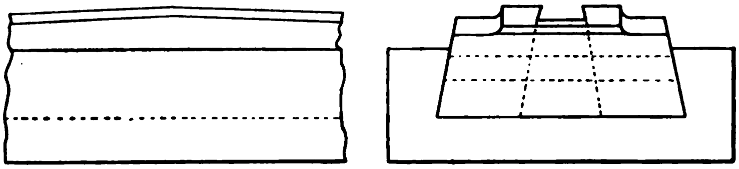


Fig. 273.

It is customary in most shops in this country to make the die to a drawing, or templet, and then harden it; after which the punch is fitted to it.

In the case of a punch for a plain die, the templet may be used in laying out the punch. If the shape of the opening in the die is the same on each side as shown in Fig. 276 and the die does not change shape in hardening the templet may be used either side next to the face of punch, but if the outline is of the form shown in Fig. 277, it will be necessary to exercise care when laying out the face of the punch from a templet, because the side of the templet placed against the face of the punch when laying it out will be opposite the one that would be placed against the face of the die when laying *that* out.

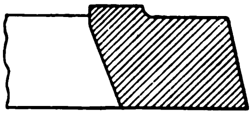


Fig. 274.

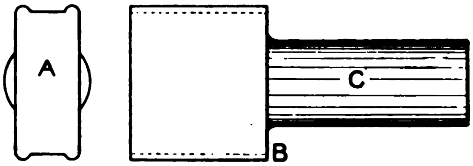


Fig. 275.

In order to obviate this trouble many tool makers lay out the face of the punch from the opening in the die before beveling the face for shear. In order to hold the punch and die together so that there will be no danger of the punch slipping while the required shape is being transferred, a die clamp of the form shown in Fig. 278 should be used.

The punch blank should be machined on both ends and the shank turned to size; the end which is to fit into the opening in the die should be finished with a smooth flat surface which should be colored with blue vitriol. After coloring, it may be clamped to the face of the die by means of the die clamp and the outline of the punch marked on the face by scribing through the opening in the die. This outline should be accurately marked with a sharp pointed prick punch as the scribed line is likely to become obliterated by the various operations of machining the punch to shape.

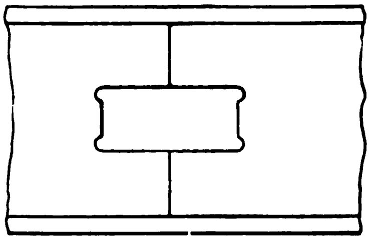


Fig. 276.

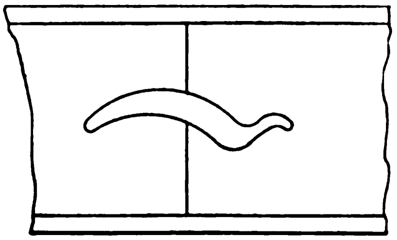


Fig. 277.

After the outline has been carefully prick punched, the punch may be milled or planed to shape leaving stock enough at all points to fit the die. If the die is to be beveled for shear, it should now be done and then hardened before fitting the punch.

The punch should be machined close to the lines and then placed over the hardened die and forced into it a little (about $\frac{1}{16}$ inch). This is termed "shearing in," and is the custom generally employed in this country.

After the punch has been sheared in for a short distance it may be removed and worked to size by means of chisel, file and scraper to the "witness" mark as the portion sheared in is termed, the operation of shearing may be repeated until the punch enters the entire length.

Fit of Punch and Die. If the material to be punched is thin or soft, it is necessary to make the punch a closer fit in the die than if the stock is heavy or very stiff. Thin stock requires a punch nicely fitted to the die in order to avoid ragged edges on the punched blank. When punching stock $\frac{1}{8}$ inch in thickness, the punch may be $\frac{1}{64}$ inch smaller than the die ; if the stock to be punched is very stiff there may be a greater difference, however, the exact amount depends on the nature of the material to be used and the character of the tool.

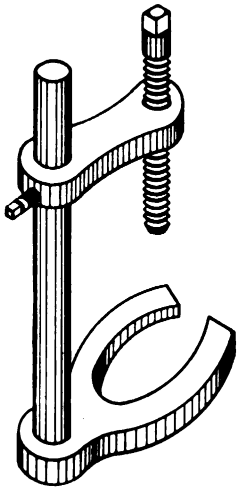


Fig. 278.

After the punch has been fitted to the die, the cutting end should be faced off to insure a good working surface and sharp edges. Any distinguishing names or marks necessary should be stamped on it, after which it is ready for hardening.

Hardening the Punch. Punches are hardened by heating in a muffler furnace, or in a clear charcoal fire, to a *low red* and cooling in water or brine, preferably the latter. Punches whose form insures strength need be hardened only on the end; the hardening should not extend quite back to the shoulder or shank. Small, slender punches are sometimes hardened the *entire* length, especially if they are to punch stock nearly as thick as the diameter of the punch; in which case the punch would become upset when used, if it were not hard the entire length.

It is generally considered good practice to have the punch softer than the die; on this account the punch is generally drawn to a color that insures this result. If a die is drawn to a straw color, the punch is drawn until it assumes a distinct purple, or even a blue color.

The punch is sometimes left soft, not hardening it at all. When this is done, it can be upset, and refitted when worn. As this would not work satisfactorily in many cases, it can be advocated only when it would be considered advisable to use a *soft* punch.

It is sometimes necessary to punch a hole in a piece of work that has been machined to some given shape. The piece is placed on the face of the die against locating points, or in an opening in a gauge plate; the opening being of the same outline as the piece of work. In Fig. 279 is shown a blank intended for a gun-sight leaf; A shows the blank before the rectangular hole is punched, while B represents the leaf after punching. The hole is punched somewhat smaller than finished size, enough stock being left to work to size with broaches.

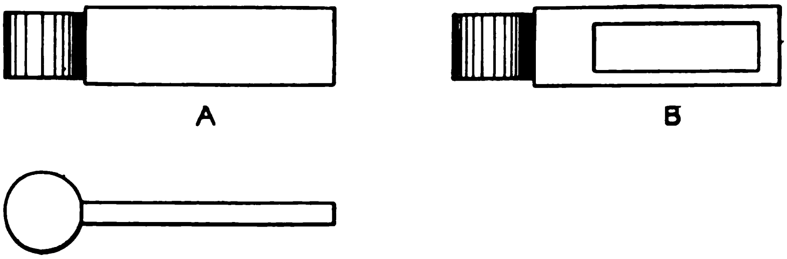


Fig. 279.

When punching work of this description, it is necessary to leave the face of the die flat; the punch is sheared as shown in Fig. 280. The piece punched from the leaf is of no value in this case, consequently the face of the punch is beveled, and the face of the die is left flat in order that the sight leaf may be straight after punching.

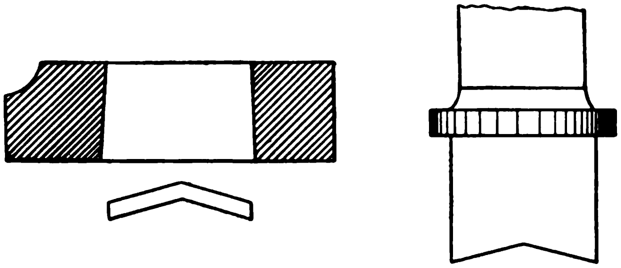


Fig. 280.

When a die and punch are to be used for an operation similar to the one described above, it is necessary to make a stripper of a form that allows the pieces to be easily placed in position and removed. As the piece which is punched is likely to increase in width from the operation, it is advisable to have stops or a guide on one side only in order to allow the piece to be readily removed after it is punched. Fig. 281 shows the same die with stripper and guide attached. The stripper is raised sufficiently from the die to allow the work to be readily inserted. A gauge pin is furnished for the end of the piece to determine the position of the slot in relation to the end. On one side is furnished a guide against which the piece rests to bring the slot central. The piece is held against the guide by means of a screw driver, a thin piece of steel, or a piece of wood.

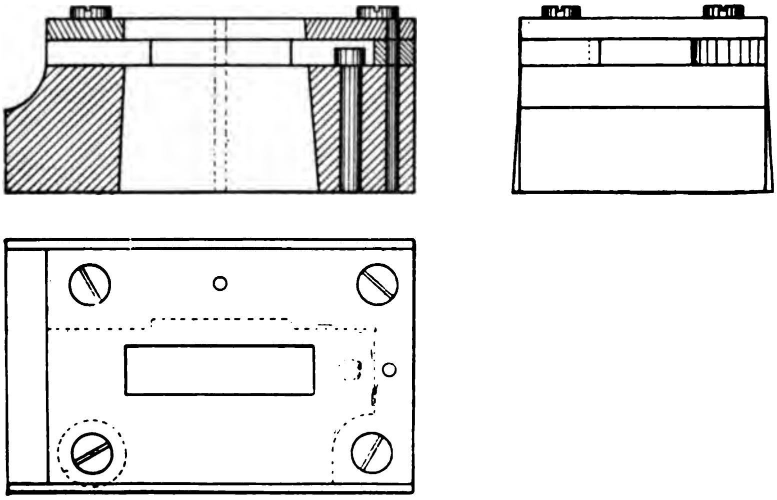


Fig. 281.

When a piece is to be punched and its size does not allow of a stripper being attached to the die as in the previous example, the stripper may be attached to the punch as shown in Fig. 282. It is made in such a manner that the stripper plate descending with the punch comes in contact with the piece being operated on and remains stationary. Between the stripper plate and the punch holder are coil springs which are compressed. The punches pass through and return. The stripper being forced downward by the action of the springs forces the blank from the punches. The gauge plate which is securely fastened to the die by means of screws and dowel pins as shown, has an opening of the same general outline as the blank but somewhat larger in order that the blank may be easily put in place and removed.

GANG DIE.

The gang die is used when punching a blank, together with any holes it is necessary to have in the blank, without being obliged to handle the pieces twice as would be the case if they were "blanked" at one operation and the holes punched at another. Two operations would be necessary if a punch and die of the form shown in Fig. 282 were used.

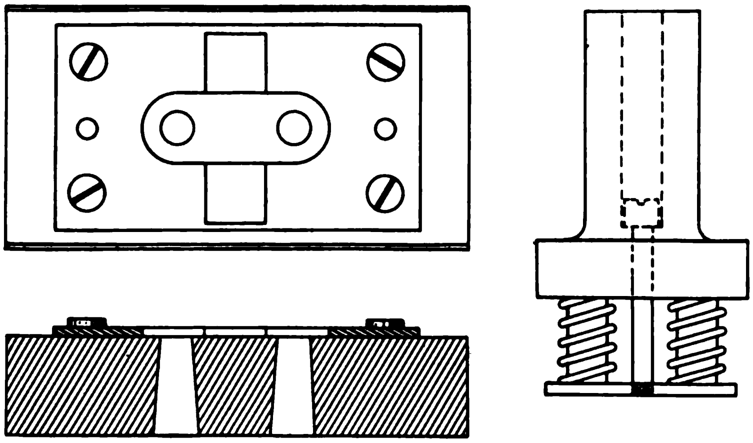


Fig. 282.

A common design of a gang die is shown in Fig. 283 which represents the piece operated on in Fig. 282. This die not only punches the holes but cuts the blank from the sheet. The stock is fed from right to left. The two holes are punched first and the stock is then fed along and the blank punched. At the same time the two holes are punched for the next blank to be cut. When the first two holes are punched in a strip of stock, the sheet is placed against the guide C, the end projecting slightly over the edge of the opening E. As the punches descend the holes F and F^1 are punched, and the end of the sheet is trimmed to length to stop at gauge pin D, which should be located about .010 inch farther to the left than the proper location for punching. The center pins as they enter the holes draw the stock back to the proper location. It is obvious that the punch A must be a trifle longer than the punches B¹ and B. Were the small punches longer than A or even of the same length they would hold the stock in such a manner that the centering pins could not locate it, and, again, the centering pins striking on one edge of the hole would spoil the blank punched and probably the pins would be broken. The centering pins must not be a tight fit in the holes or the punched blank will stick to the pins and return with the punch. By carefully fitting the pins to a punched hole they may be fitted close enough to insure punching within a very small limit of variation. In fact for most classes of work it is possible to punch near enough to standards for all practical purposes.

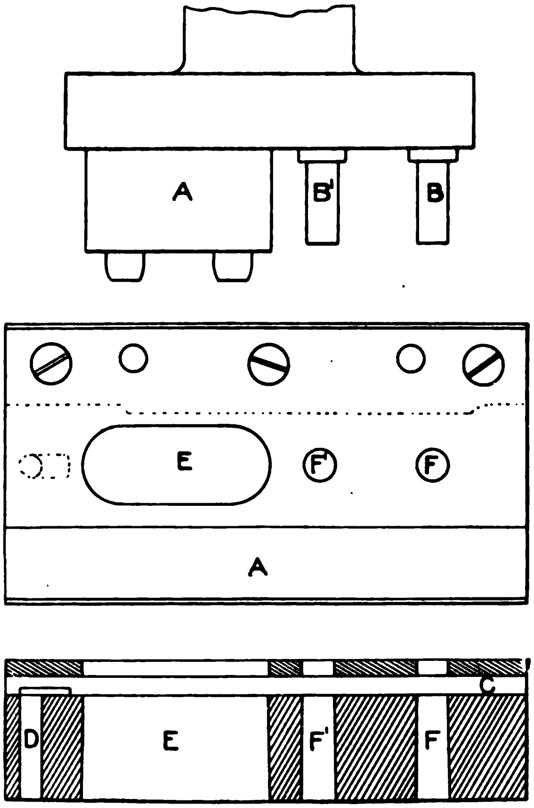


Fig. 283.

When punching work with gang dies of the design shown in Fig. 283, it is easily seen that in the case of work being punched from strips wider than is necessary to get out two punchings, the scrap left between must be removed by some means. This is frequently done by a large lever shear, or a pair of power shears; this is a costly operation where many pieces are punched at a time. To do away with this extra cost, dies are made having an extra opening and a punch working into this cuts away the surplus stock, or scrap, leaving the edge of the sheet straight and in condition to rest against the guide. In Fig. 284 the opening A is the

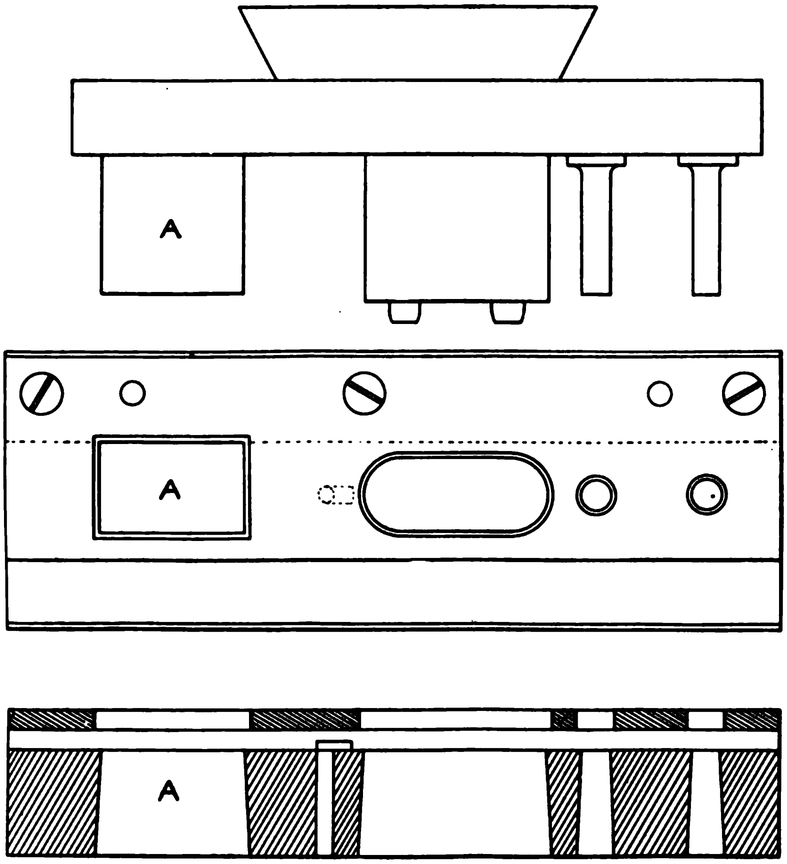


Fig. 284.

trimming die; the punch working in this cuts away the scrap leaving the edge of the sheet straight.

MULTIPLE DIE.

When making a die for punching pieces whose outline will allow it, it is sometimes advisable to make several openings of the same outline so arranged that as many pieces may be punched at a time as there are openings in the die block. If the work is punched in large quantities a great saving can be effected in the cost of production by the use of this form of die.

Where perforated sheet metal work is manufactured it is customary to make dies having as many as 500 punches working into one die block at a time, but as this is an unusual application of this principle it will not be considered.

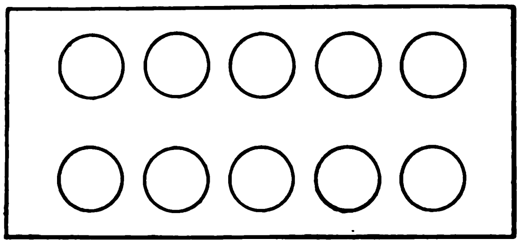


Fig. 285.

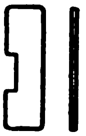
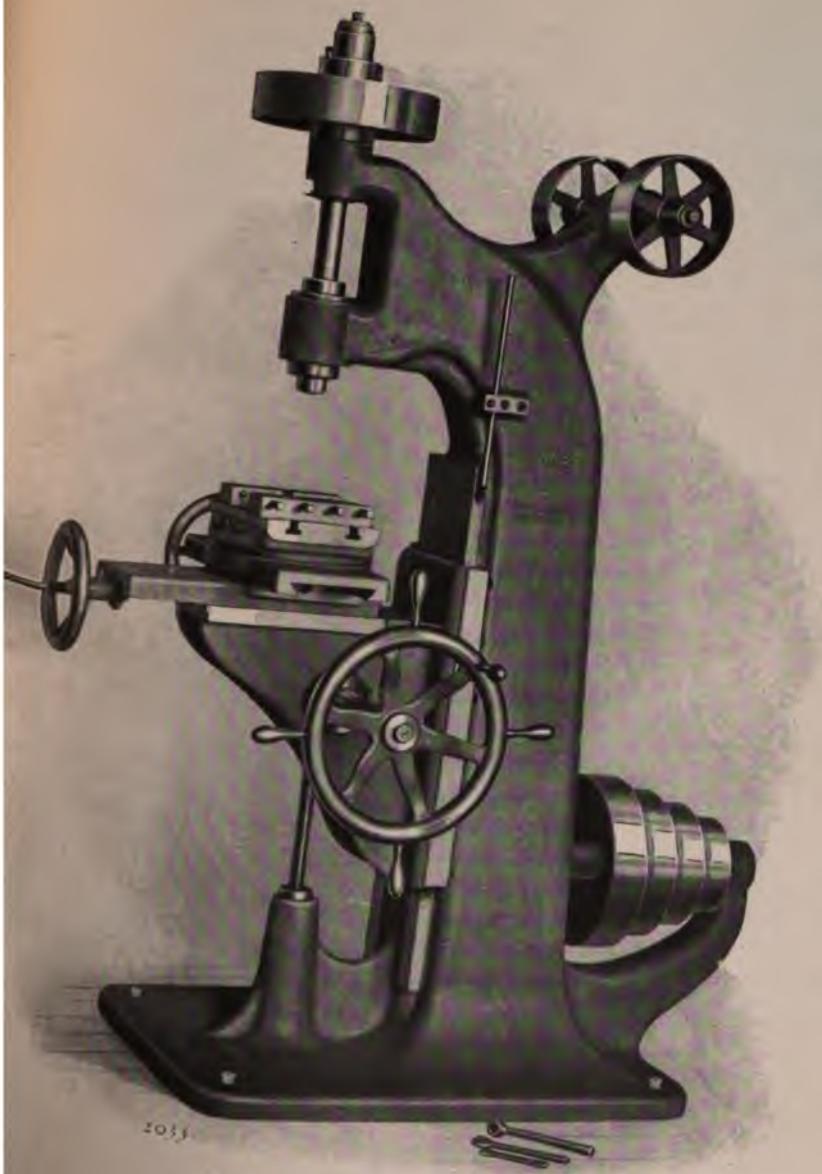


Fig. 286.

If it is necessary to punch 10 holes in the piece shown in Fig. 285 a die can be made having this number of openings. Then by making a punch holder having an equal number of punches properly located all the holes can be punched at one stroke of the press.

While in the case just cited the piece of stock which had the holes punched in it is the product, the punchings being scrap, the same principle may be applied to punching blanks from a sheet of stock by means of a multiple die.

The design shown in Fig. 286 is the product in a shop wher many thousands of this piece are used monthly. The die produc a dozen or more blanks at each stroke of the press; but for co venience in illustrating the die and punches, it shows but fc openings ir [illegible] nding number of punches. Fig. 2



DIE SINKING MACHINE.
Pratt and Whitney Co.

If a die were made with the openings near enough together to punch the stock as shown in Fig. 288 there would be so little stock between the openings that the die would not stand up when used; for this reason the openings are located in such manner that every other opening shown in Fig. 288 is omitted. When the punch descends four blanks are punched; the stock is moved until the first opening strikes the gauge pin. This leaves the stock in position to punch between the openings already made, thus preventing waste. The next time the stock is moved until the gauge pin strikes the wall of the last opening to the right.

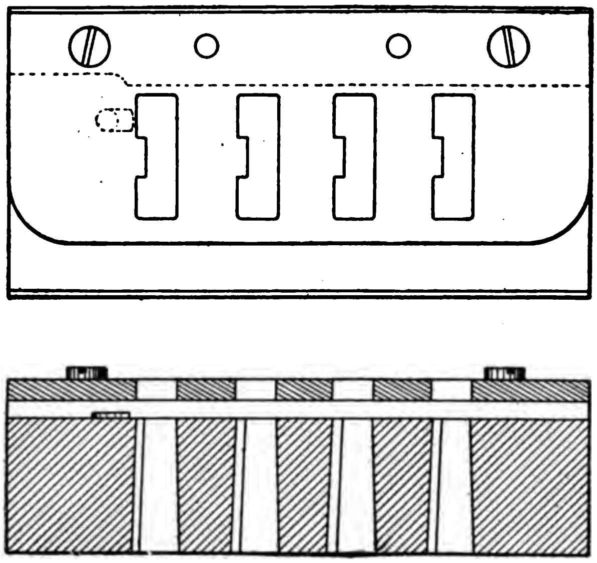


Fig. 287.

BENDING DIE.

In order to bend metals to various forms, dies are made for use in punching presses, drop hammers and various other machines. A simple form of bending die is shown in Fig. 289. The shape of the upper and lower parts of the die is such, that when the upper part is brought down on the blank B (shown by the dotted lines) it will be bent to the required shape. The shoulder A forms a locating stop against which the blank rests before bending.

When making bending dies for extremely soft metals, the dies may be made of the exact shape of the model, or the shape the piece should be when finished; but if the pieces are made from stiff material which bends with difficulty, it will be necessary to make the die of a form that will give the article more bend than is required as it will spring back some as soon as released by the return of the upper part.

Compound Bending Die. In Fig. 290 is shown a form of bending die used in bending bow spring and looped wire for armature connections or other looped wire work. The work is placed in the die, and the punch, as it descends, bends the wire to the shape of the die. The spring just back of the punch is compressed thus allowing the punch holder to descend and force the side benders BB toward the punch by means of the wedge pins AA, thus forming the piece in a circle.

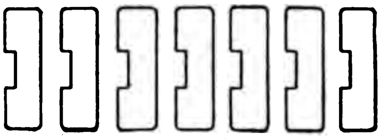


Fig. 288.

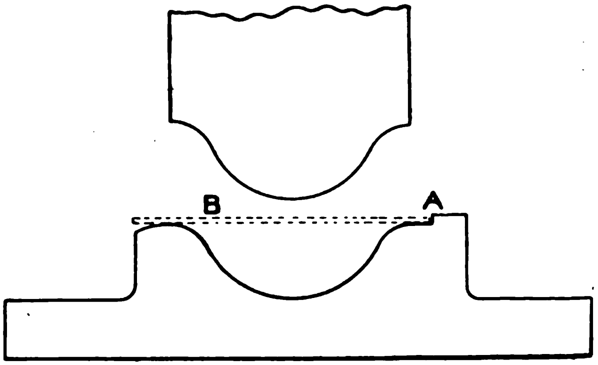
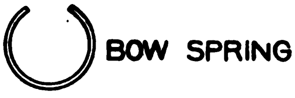


Fig. 289.

It is obvious that it is necessary to make the shape of the punch and die different. The lower die must have its bending surface, a curve of a radius equal to that of the punch plus the thickness of the material.

FORMING DIE.

This type of die is familiarly known as a *drawing die*. Th most common examples of *forming* die is that [illegible] drawing flat circular blank, as shown at A, F [illegible] piece, as shown at B. This operation can be done in an ordinary punching press by means of a forming die of the shape known as a push through die, from that fact that the piece is formed to shape, and pushed through the die at one operation. This form of die is shown in Fig. 292. The face of the die is cut to receive the blank; this depression is known as the *set edge*. The opening in the die is given a "draw" of $\frac{1}{4}$ to $\frac{1}{2}$ of a degree making it larger at the top, the upper edge is rounded over and left very smooth. The bottom edge of the opening is made very sharp in order that the piece may not be carried back with the punch as it returns.



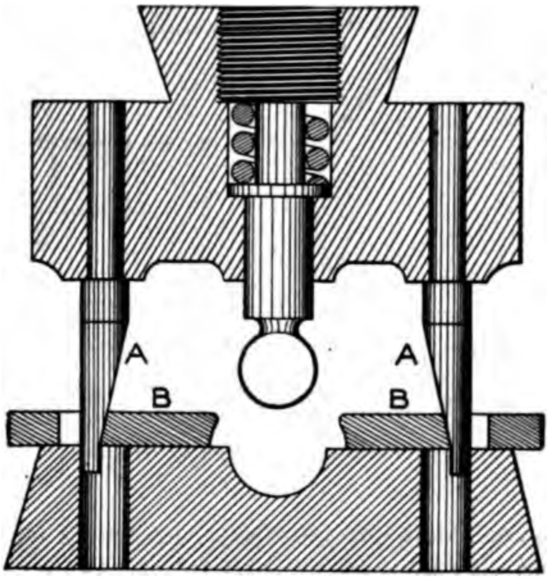


Fig. 290.

This form of die is left as hard as possible, and the walls of the opening are made as smooth as they can be polished. It is sometimes advisable to finish the walls with a lateral rather than a circular finish.

MAKING GAUGES.

Gauges are used in machine shops in order that a part of a machine, apparatus, or tool may correspond with some other part, so that when it is assembled every part may go in its place with little or no fitting.

In shops where work is made on the interchangeable plan, that is, a piece of work made to-day will exactly duplicate a similar piece made at some time in the past, a very thorough system of inspection is necessary. In order that the inspection may accomplish the desired result, gauges are made that show any variation of the pieces from a given standard.

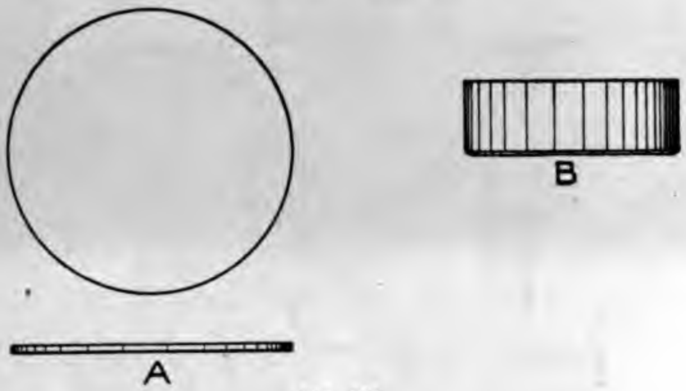


Fig. 201.

There are several forms of gauges in use for various classes of work, but only those in common use in the general machine shop will be considered here.

Gauges are generally made of *tool steel*; but *hardened tool steel* has a tendency to change its size or shape at a considerable time after the hardening takes place. This change is ascribed by acknowledged authorities, to a rearrangement of the minute particles or molecules of the steel, whose original arrangement had been changed by the process of hardening. While this change of size or shape is small, so small indeed, that it need not be considered except in the case of gauges where great accuracy is required, yet it has led some manufacturers to use machinery steel.

If tool steel is used, the tendency to change its shape may be overcome to some extent by grinding the gauge to within a few thousandths of an inch of finish size and allowing it to "season" as it is termed among mechanics; that is, it is laid aside for a few months or a year before finishing to size. This method is open to serious objection if one is in a hurry for a gauge.

To save time, it is customary in many shops to draw the temper to a straw color, allowing the gauge to cool off slowly; this operation is repeated several times. It is necessary to brighten the steel each time before drawing the temper in order that the colors may be readily seen; as this very materially softens the gauge it will not last as long as if left hard.

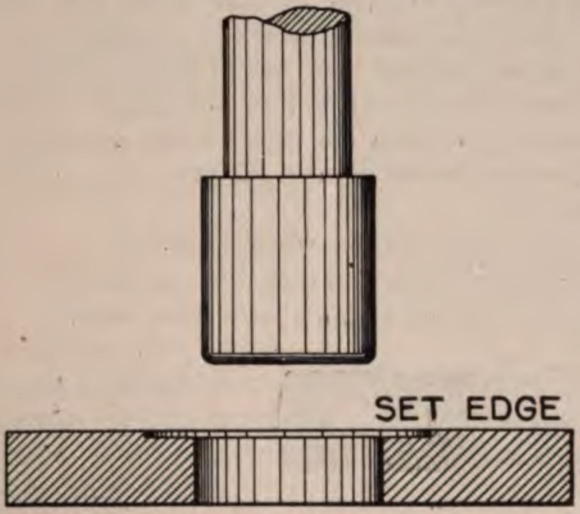


Fig. 292.

Accuracy in Gauge Making. When making gauges the workman should observe the points emphasized under "Approximate and Precise Measurements." While gauge making is generally considered very accurate work, unnecessary accuracy should not be used. If a gauge is intended for work where a variation of .005 inch is permissible, it is folly and a needless waste of time to make the gauge within a limit of variation of .0001 he other hand if the gauge is to be used as a test gauge on work requiring *great accuracy* it is necessary to use every possible effort to make it accurate.

If a gauge is to be made of tool steel, it is necessary to first remove all the outside portion (skin) of the stock, and "block" the gauge out some where near to shape; it should then be thoroughly annealed. If the gauge is flat, and should spring while annealing it *should not* be straightened cold, as it would be almost sure to spring when hardened.

It is necessary to stamp the name of the part to be gauged and the sizes of the different parts of the gauge. The workman should bear in mind that the effect of driving stamps, letters, or figures into a piece of steel will be to "stretch" it, consequently it is advisable to stamp the gauge before finishing any of the gauging portions to size, even if the gauge has an allowance for grinding.

PLUG AND RING GUAGE.

Plug gauges are used to gauge the size of a hole, while a ring gauge is for measuring a cylindrical piece of work.

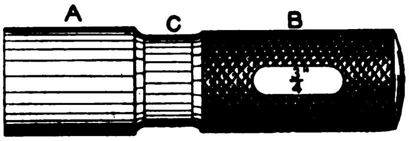


Fig. 293.

To make a plug gauge as shown in Fig. 293, stock should be selected enough larger than finish size to allow for turning off the decarbonized surface. After roughing out, the handle B should be turned to size and knurled, the portion C should be turned to size and finished, the spot in the center of the handle should now be milled and the size of the gauge and any distinguishing mark or name of the article to be gauged should be stamped as shown. Or, as is the custom in many shops, the stamping may be done at C. After stamping, the gauge end A may be turned to a size .010 or .015 inch larger than finish to allow for grinding. Plug gauges should be heated very carefully for hardening, remembering that the lower the heat, the more compact will be the grain, and a piece of steel whose grain is fine and compact will wear
better than one whose If the gauge is one requir-
ing great accur 08 inch above size
and allowe deemed neces-

sary; if not it may be ground to a size .001 inch larger than finish, after which it must be lapped to finish size. When grinding a gauge of this description, it is advisable to use a grinding machine having a supply of water running on the work to keep it cool, but if this form of grinder is not available, the gauge should not be heated any more than is necessary. The gauge should be measured while cold, as steel always expands from the action of heat, and a gauge ground to size when heated would be too small after it had cooled.

When grinding work of this nature, it is advisable if possible to use a form of grinder having two dead centers, that is, one in which neither center revolves. This is mentioned on account of the tendency in some shops where there is no universal grinder, (and an engine lathe is to be used as a grinder) to select the poorest lathe in the shop for the purpose. Lathes that have been in use for some time are very likely to have become worn, so that accurate work is impossible; this is especially true of the head spindle which will duplicate its untruth on the piece being ground.

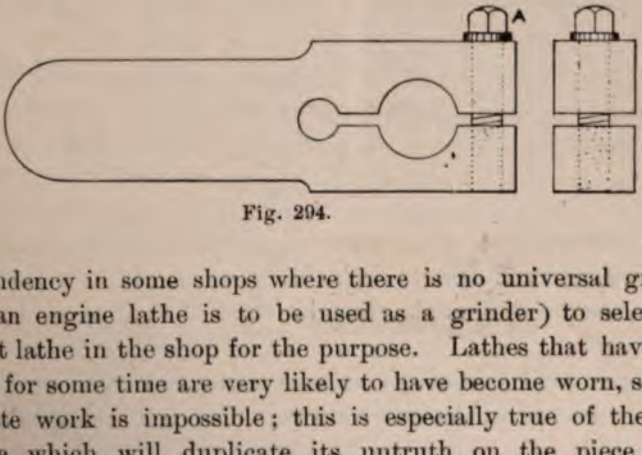


Fig. 294.

If obliged to use a machine of this description, it is advisable to leave a trifle more stock for lapping than if a suitable grinder is at hand. When grinding, a coarse wheel free from glaze should be used to grind within .004 of finish size, after which a finer wheel may be substituted to grind to lapping size.

A very simple method of making a lap for lapping a cylindrical surface is shown in Fig. 294; this consists of a piece of cast iron having a hole bored a trifle larger than the size of the [illegible] round. It is split as shown, and is closed by means [illegible]

[illegible] much gauge, or similar work, requiring lapping it is advisable to make a lap as shown in Fig. 295. The holder A has a hole bored to receive the laps which are made in the form of rings fitting the holder as shown; these rings are split in three places. One cut is carried *through* one wall, while the other two commencing at the inside, terminate a little distance from the outside surface. The laps may be held in place by means of the pointed screw shown at B.

The lapping should be done with flour emery mixed with oil. This operation has the effect of heating the gauge to a degree that would make it unsafe to caliper. On this account it is necessary to have a dish of water handy in which to cool the gauge before measuring it. This water should not be *cold*, or incorrect measurements will result; it should be as nearly as possible the average temperature of the room in which it is to be used, (about 70 degrees).

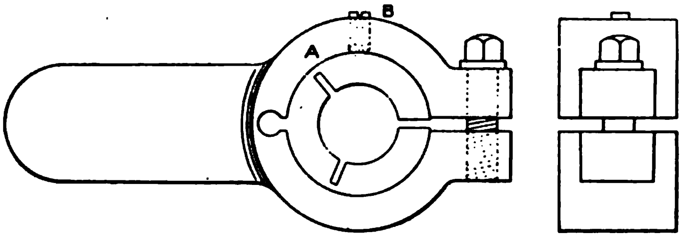


Fig. 295.

When plug gauges are made of machinery steel they should be case hardened in the following manner. They may be packed as for "Pack Hardening"; that is, using charred leather as the packing material. They should run in the furnace for 7 or 8 hours; *after* they are red hot, the box should be taken from the furnace and allowed to cool, after which the gauge may be heated in an ordinary fire enclosing it in a piece of tube. When it reaches a low red heat, it should be plunged in a bath of raw linseed oil. It will not be necessary to draw the temper, and the danger of alteration as it ages is done away with.

The reason for not hardening when the gauge has run the required length of time in the furnace is that the effect of the *second* heat is to refine the steel, making the grain more compact, like *properly* hardened *tool steel*, thus increasing its wearing qualities.

After the gauge has been lapped to the required size, it may be placed in a chuck on the grinding machine and the end ground off to remove any portion that is slightly smaller than the balance of the gauge, as the lapping is likely to grind the extreme end slightly tapering. In order to save time when grinding the end, the gauge may be made as shown in Fig. 296. The sectional view shows the end cupped in, leaving a wall $\frac{1}{16}$ inch to $\frac{1}{8}$ inch thick according to the size of the gauge, the larger sizes having the thicker walls; the cupping should be about $\frac{1}{16}$ inch deep and the corner left slightly rounded as shown.

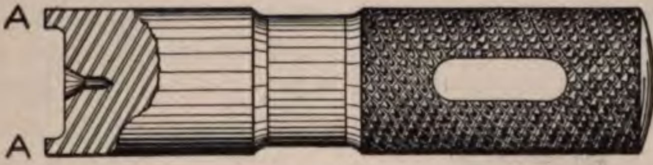


Fig. 296.

Another method is to cut a groove with a round nose cutting off tool leaving a disc on the end as shown in Fig. 297. If the gauge has its end shaped as shown in Fig. 296, the projecting end A A is ground away until the end of gauge is straight across. In case it is made as shown in Fig. 297, the disc A is broken off and the end ground as described.

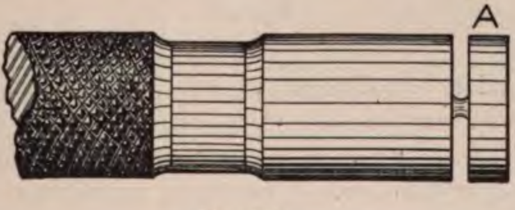


Fig. 297.

RING GAUGE.

Ring gauges intended for gauging cylindrical pieces smaller than 1 inch diameter are generally made of a solid piece of tool steel, or machinery steel which may be case hardened. For a gauge 1 inch or larger custom varies, some tool makers making it of a solid piece, while others make the body of cast iron, or machinery steel, into which is forced a hardened bushing which is the gauge proper.

It is advisable when making a solid gauge to use a piece of steel somewhat longer than finish dimensions as shown in Fig. 298. The dimension A representing the *finish* length of gauge; the projections B B being left until the gauge is lapped to size. The hole should be bored somewhat smaller than finish size in order to allow for grinding and lapping. If a grinder having an internal grinding attachment is not available, the allowance should be much less than if it were possible to grind the walls of the hole. If the gauge is to be ground to size an allowance of .005 inch will be sufficient; if not to be ground and the hole is bored straight and smooth, allow .0015 to .002; but the amount left cannot be given arbitrarily, as much depends on the condition of the hole, and the care used in hardening.

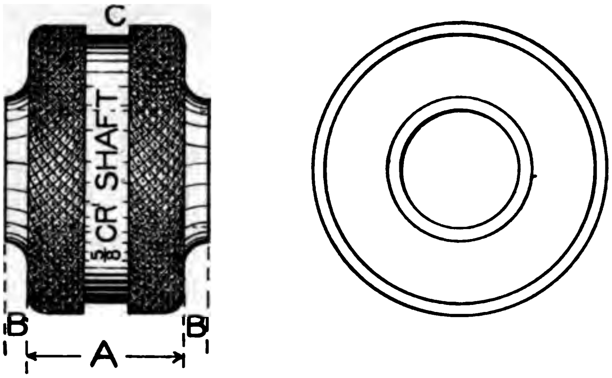


Fig. 298.

After boring the hole the blank may be placed on a mandrel the ends shaped as shown in Fig. 298, the outside diameter turned and knurled, and the portion C necked to the bottom of the knurling. The size and any distinguishing marks may be stamped on this necked portion as shown. The gauge is now ready for hardening; much better results may be obtained if the gauge is pack hardened. If this method cannot be used, the gauge should be carefully heated in a muffler furnace or in a piece of gas pipe or iron tube in an ordinary fire. When it reaches a *low uniform* heat it should be plunged in a bath of brine and worked around so that the bath may circulate freely through the hole; excellent results can be obtained if a bath is used having a jet of brine or water coming up from the bottom and passing through the hole with some force in order to remove any steam that may be generated.

If it is considered necessary to allow the gauge to "season," the hole may be ground enough to remove part of the allowance, and the gauge laid away. If it is not considered necessary to do this it may be ground .001 or .0015 inch smaller than finish size to allow for lapping.

When lapping a ring gauge to size, it is necessary to use a *suitable* lap. A poor lap is the cause of many of the failures when attempting to do satisfactory work of this description.

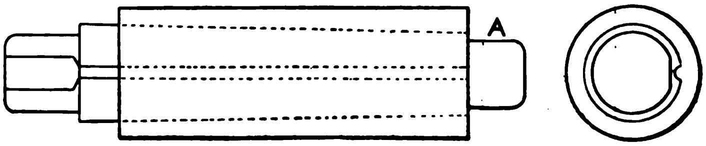


Fig. 299.

When a grinder having an internal grinding attachment is not available, and it is found necessary to leave considerable stock in the hole for lapping, many tool makers claim best results from using two laps; the first, a lead lap, for removing most of the stock; and the second, a cast-iron lap for finishing the hole to size. In either case, the lap should be in the form of a shell which should be held on a mandrel when in use. Fig. 299 shows a lead lap on a mandrel as described.

The mandrel should be made with the ends somewhat smaller than the body which should be tapering in order that the lap may be expanded as it is driven on. A groove is cut the entire length of the body with a convex milling cutter, or it may be cut in the shaper or planer, holding the mandrel between centers or in the vise, cutting the slot with a round-nosed tool. A
casting the lead to shape may be made of two pieces of
nch or two longer than the desired length of lap which

should be three times the length of the hole in the gauge. The two pieces of wood should be clamped together, and a hole bored with a bit about $\frac{1}{8}$ inch larger than the diameter of the finished lap; after boring to the required depth, a bit should then be used the size of the projection on the small end of the mandrel; the hole bored with this bit should be a trifle deeper than the length of the projection. After the hole has been bored in the mold as described, the mandrel may be put in position as shown in Fig. 300 with the mold in a vertical position. Two narrow strips of wood or metal are placed on top of the mold to hold the mandrel central in the mold. In order that the lead may *run* well, it will be necessary to heat the mandrel somewhat; this should be done before putting it in the mold.

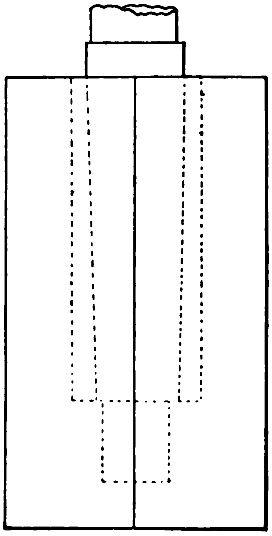


Fig. 300.

After the lead has become cool the mold may be opened, and the casting removed. It should be placed in the lathe on the mandrel, and turned to a size .001 inch smaller than the hole in the gauge; it may then be charged with emery, using fine emery and oil.

For finishing the hole to size, or lapping a hole *ground* nearly to size, it is advisable to use a lap made of harder material than lead; for this purpose fine-grained cast iron answers admirably, although copper is preferred by some. In order to make a cast-iron lap, a mandrel is necessary, which should taper $\frac{1}{8}$ to $\frac{3}{16}$ inch per foot of length. The slight taper is used in order that the lap may not increase its size too rapidly when driven on the mandrel. The cast-iron lap (sleeve) should be bored with a taper corresponding to the taper of the mandrel, after which it may be forced on the mandrel and turned to size and split as shown in Fig. 301. One slot should extend through the wall as shown at A (end view), while the other two slots B B extend deep enough to allow the lap to expand hing the hole to size the lap should b mandrel, and trued in the grinder using an emery wheel to cut the lap. The lap should be *perfectly round* and *straight*, in order to produce true holes. For the finish lapping the finest of flour emery should be used. The same precautions should be observed while cooling the gauge before trying the size of hole, as were noted under "Lapping Plug Gauges." In order to clean the gauge of the oil and emery, it should be dipped in a can of benzine, which readily removes any dirt. Extreme care should be exercised when washing work in benzine that it is not brought in the vicinity of a flame of any kind, as it is *extremely* inflammable, and very difficult to extinguish if it becomes ignited; should it become ignited it can be extinguished with a piece of heavy sacking.

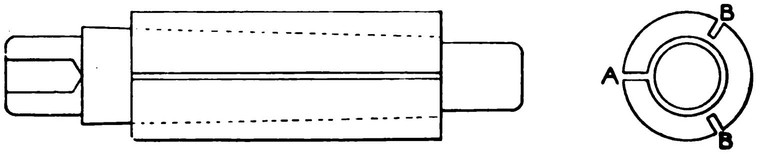


Fig. 301.

The ring should be fitted to the plug gauge which has previously been finished to the correct size. It must be borne in mind that the temperature of the plug and ring should be as nearly the same as possible when testing.

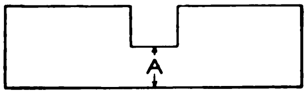


Fig. 302.

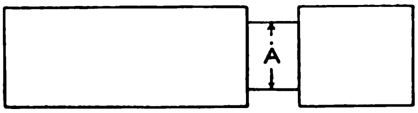


Fig. 303.

SNAP GUAGE.

This form of gauge is used more extensively than any other for outside measurements; it is extremely useful in gauging a dimension between two shoulders as shown at A, Figs. 302 and 303; in the former case the piece being machined is flat while in the latter it is cylindrical.

Snap gauges may be designed to meet the requirements of the particular piece of work upon which they are to be used. When a gauge of this description is intended for use on a cylindrical piece, the opening should be made a trifle deeper than one-half the diameter of the piece to be measured.

When a snap gauge is intended for flat work, the depth of the slot depends on the nature of the work.

Snap Guages for Cylindrical Work. As previously stated when snap gauges are to be used for gauging cylindrical pieces it is necessary to make the opening a trifle deeper than one-half the diameter of the piece to be measured, as shown in Fig. 304, in which A represents the cylindrical piece to be gauged.

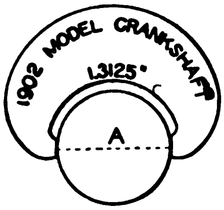


Fig. 304.

When making a snap gauge of this form the stock should be blocked out somewhere near to shape and annealed; after annealing the sides may be made flat and parallel, and the size and any distinguishing marks stamped as shown, after which the gauge part may be worked to a size .008 to .010 inch smaller than finish to allow for grinding. The outer edges should be rounded somewhat to prevent cutting the hands of the operator.

When hardening gauges of this type, some tool makers harden only the prongs that come in contact with the work, while others harden the entire gauge. If the contact points alone are to be hardened, the heating can best be done in a crucible of red-hot lead, but if this is not at hand a piece of flat-iron may be placed each side of the gauge, allowing the ends to be hardened to project beyond the pieces; the whole may now be grasped in a pair of tongs, and placed in the fire. The points will reach a hardening heat before the portion between the flat pieces is very much heated. It may be plunged in wat rine to harden.

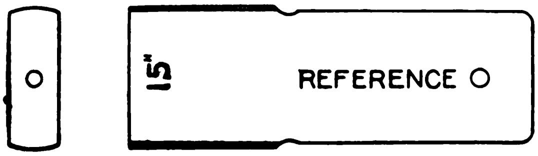


Fig. 305.

If it is consider
harden the gauge all over, it
should be heated
that th
blast does not

heat. When it reaches a low red heat remove from the fire and plunge in the bath; if the gauge is quite thin a bath of oil will harden sufficiently; if it is dipped in water or brine the bath should be warmed somewhat in order to avoid as much as possible any tendency to spring.

After hardening, the gauge is ground to a size .0005 inch smaller than finish and lapped to size; the method used in grinding gauges of this character will be described later.

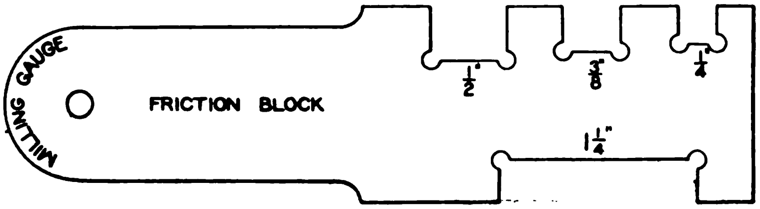


Fig. 306.

In order to be able to give gauges the correct size, it is often necessary to make male gauges. The simplest form of male gauge is shown in Fig. 305; it is a flat piece of tool steel, made slightly small on one end to avoid grinding to size the entire length. After hardening the large end, it is ground to size; it is then ready for use in testing the size of the female snap gauges while the latter are being lapped to size; or when grinding if lapping is not considered necessary. When it is necessary to make a snap gauge for gauging two or more dimensions on a piece of work, the gauge may be made as shown in Fig. 306, while Fig. 307 represents the piece to be gauged.

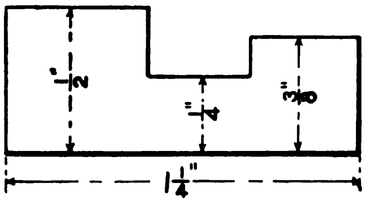


Fig. 307.

After cutting off the steel for the gauge, the sides may be planed to remove the "skin." One of the flat surfaces may be colored with blue vitriol, or it may be colored by holding over a fire until the surface becomes blue. The handle and the openings that constitute the gauges may be laid off on the surface. After milling the handle to shape the holes shown at the corners of the openings may be drilled; these holes facilitate the operations of filing and grinding, particularly the latter. The openings may be milled or planed to a size somewhat ($\frac{1}{32}$ inch) smaller than finish and the gauge is ready for annealing. After it is annealed the two flat surfaces may be planed or filed until flat and parallel. The name of the piece to be gauged and the size of the openings may be stamped as shown. If the gauge is intended for gauging work where a few thousandths of an inch either way would make

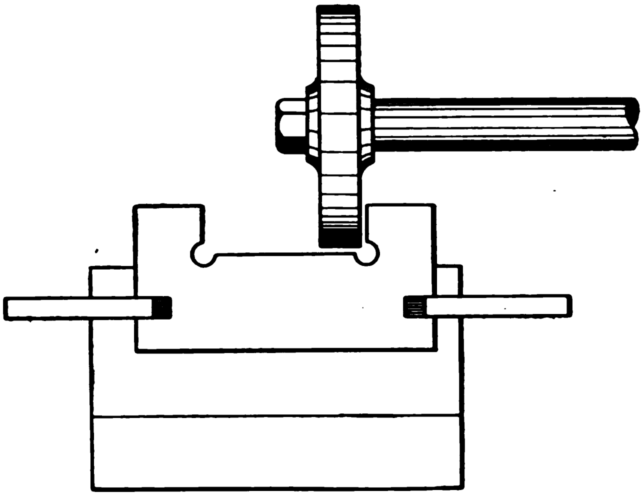
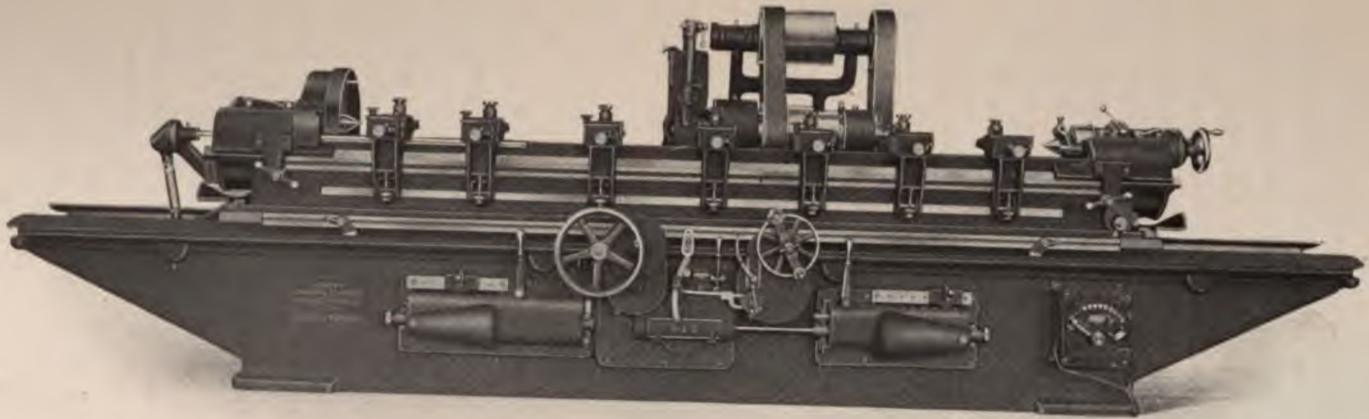


Fig. 308.

no particular difference, it is customary to make the openings to the given sizes before the gauge is hardened. However, if the gauge must be exact to size, it is necessary to leave from .003 to .005 inch on each measuring surface to allow for grinding, and if it is desirable to have the gauge retain its exact size for any considerable length of time, it will be found necessary to finish the gauge to size by lapping *after* it is ground.

Grinding Snap Gauges. Snap gauges may be held in a vise on the universal grinder when grinding the openings to size provided the gauge is held in such a manner that it cannot spring. If it were sprung in any manner while being held, it would assume its normal shape when taken from the vise, and consequently the measuring surfaces would not be parallel. This would destroy



FRONT VIEW OF GRINDING MACHINE SHOWING ELECTRIC DRIVE.
Norton Grinding Company.

the accuracy of the gauge, as it is highly important that the measuring surface of the opening be parallel.

A snap gauge may be clamped to an angle iron which may be held, while grinding, in the vise as shown in Fig. 308, or it may be clamped to a piece of machinery steel or cast iron which is centered as shown in Fig. 309. This holder should be placed between the centers of the grinding machine.

If the opening whose gauging surfaces are to be ground is of sufficient width, an emery wheel of the form shown in Fig. 310 may be used, or a wheel may be recessed on its sides as shown in Fig. 311. If a wheel of the form shown in Fig. 310 is used it will be necessary to remove the wheel after grinding one wall of the opening and reverse it to grind the other. If, however, the opening is too narrow to allow a wheel of the form shown above to be used, a very thin wheel may be made to answer the purpose, but it will be necessary to swivel the head of the grinder a little in order that the wheel may touch the surface to be ground only at the corner of the wheel.

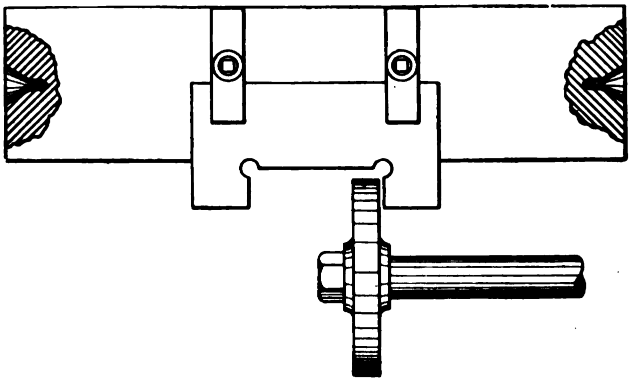


Fig. 309.

If a grinding machine is not available, an engine lathe or a bench lathe can be used. If the lathe is provided with a grinding attachment, the holder to which the gauge is attached may be placed between the centers of the lathe, and the grinding attachment used in the ordinary manner. If the lathe is not provided with a grinding attachment the emery wheel may be mounted on an arbor between the centers of the lathe. The arbor may be driven from any accessible pulley either on some overhead countershaft or some machine having a pulley in line with a small pulley on the arbor, on which the driving belt is supposed to run. If this method is used it will be necessary to have hardened centers in both head and tail spindles. If a *thin* wheel is used in grinding the surfaces of a narrow opening, the tail center of the lathe may be set over each way to give the desired amount of clearance to the side of the emery wheel. The holder mentioned may be fastened to the tool rest, or the gauge may be fastened to the rest as shown in Fig. 312. At the right is shown a side view of one of the clamps used in holding the work to the rest while grinding; the center is represented as being cut away in order that it may bear at its ends thus removing any chance of its tipping the work being ground.

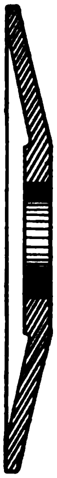


Fig. 310.

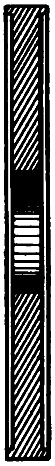


Fig. 311.

Lapping a Gauge to Size. Where it is essential that gauges retain their exact size for a considerable length of time, the gauging surfaces must be lapped to size after grinding. The surface left by the emery wheel, even when the utmost care is used, consists of a series of small ridges or irregularities which wear away as the gauge is used and leave the opening too large; lapping the gauging surfaces with oil and emery grinds these minute particles away, leaving a perfectly flat surface, thereby increasing the durability of the gauge.

A convenient form of lap for use in lapping the gauging surfaces of snap gauges is shown in Fig. 313. It consists of a piece of copper or brass wire, bent as shown; the surface A is filed or hammered flat and charged with some abrasive material, as emery; extreme care must be used in lapping the surfaces that they remain perfectly flat and parallel. Unless the operator [illegible]
erable experience in this particular br[illegible]
be likely to cut the edges away
doing this, pieces of hardened

of the gauge before grinding, as shown in Fig. 314. As the tendency when lapping is to make the outer edges round, the portions rounded will be the edges of the pieces clamped to the gauge. After the gauge has been lapped to size these pieces may be removed.

Adjustable Snap Gauge. Snap gauges that are in *constant* use soon wear to an extent that renders them useless, making it necessary to close them in and grind and lap them to size again, or else replace them with new gauges. This tendency to wear and the consequent labor and cost of resizing or replacing has caused the adoption of a style of snap gauge whose size could be altered when necessary; this form of gauge is styled an adjustable snap gauge.

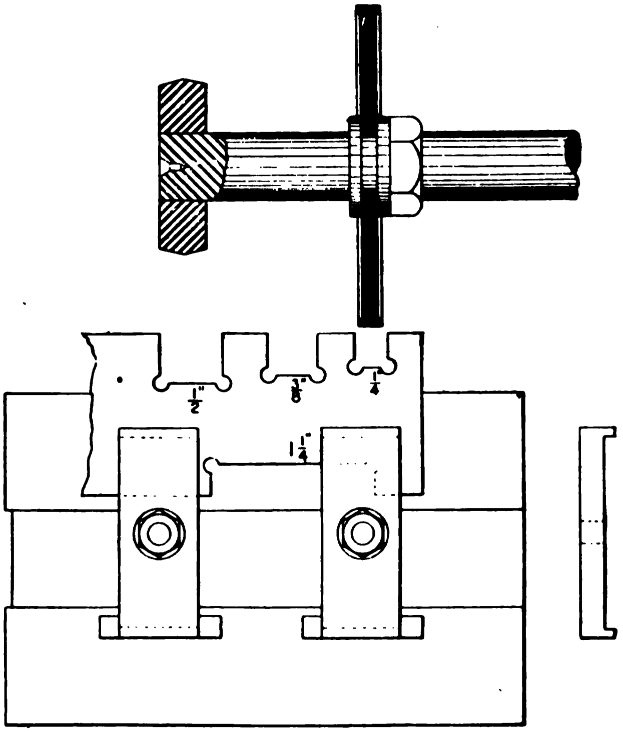


Fig. 312.

The method of adjustment differs in different shops. Fig.

315 represents a form of adjustable snap gauge which is not expensive and gives excellent results in that its size may be readily adjusted. After blocking out the gauge somewhere near to shape, the screw hole for the adjusting screw C should be drilled and tapped, and the slot milled for the adjustable jaw. The jaw should be made as shown having a slot through which the binding screw D may pass. The jaw should fit snugly in the slot in the frame and placed in position after stamping the name and any distinguishing marks. The aperture E should be worked to a size .010 or .015 inch smaller than finish. The adjustable jaw B may now be removed and the gauging (or contact) surface hardened, being careful not to harden the entire length of the large portion or a crack may appear in the sharp corners on account of the unequal size of the two portions. In order to heat the contact surface and not heat back into the sharp corners, the face may be immersed in red-hot lead, leaving just long enough to sufficiently heat the face; or the smaller portion may be held in a pair of tongs letting the end of the jaws come against the shoulders of the piece. It may then be heated in a gas jet or ordinary [illegible] it will not be necessary to harden [illegible] portion A is hard

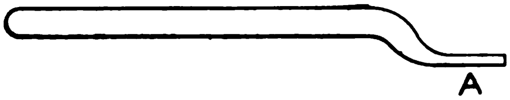


Fig. 313.

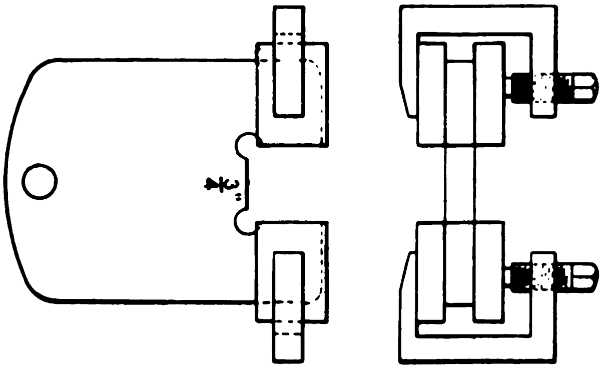


Fig. 314.

ened it will be found sufficient. After hardening, the gauge may be assembled and ground and lapped as already explained.

LIMIT GAUGE.

Where it is not necessary that work be of exact size, and a small limit of variation is permissible, limit gauges are used. They prevent a waste of time in attempting excessive accuracy, yet leave the work so that the corresponding parts when brought together will fit well enough to meet requirements.

These gauges are also valuable in roughing work for finishing.

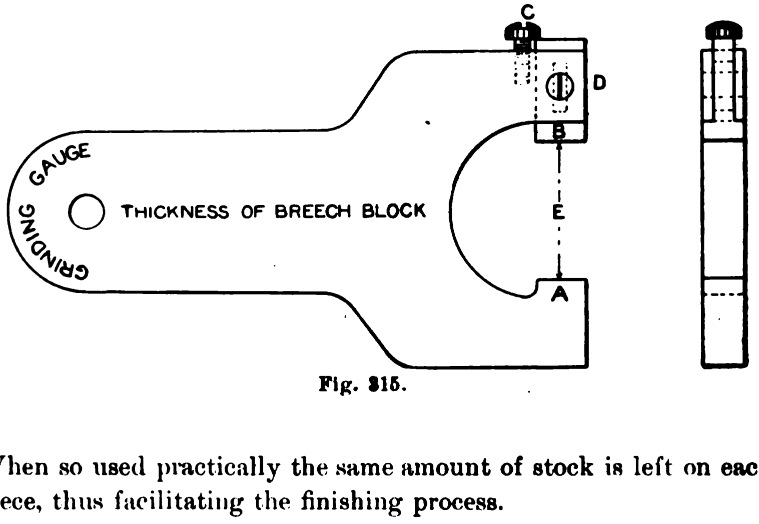


Fig. 315.

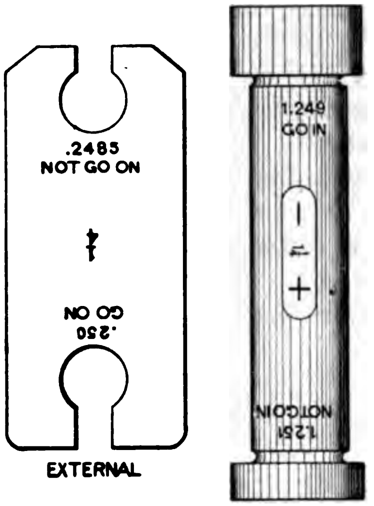
When so used practically the same amount of stock is left on each piece, thus facilitating the finishing process.

If a cylindrical piece is to go in a reamed hole, and the piece fits well enough for all requirements when .003 inch smaller than size of hole, it is folly to spend the time necessary to get a more accurate fit.

The amount of variation allowable must be decided in each case; on one job a limit of variation of .001 inch might be all that could be allowed, while on another piece of work .010 inch might be allowable.

In deciding the allowable limit of variation it is advisable, where it is possible, to take into consideration the natural changes that take place in a gauge from wear. For instance, suppose a piece of work .250 inch in diameter just fills the hole it is to go in, and a limit of .0015 inch is allowable; that is, if the piece is

.2485 inch to .250 inch diameter, it would be folly to make the large end of limit gauge for this work .250 inch as there would be no allowance for wear of either the external or internal gauge.



EXTERNAL

INTERNAL

Fig. 316.

Fig. 316 gives an idea of one form of a snap gauge used for external measurements; however, it is not necessary to make them of the styles shown. The plug gauge may be made as shown in Fig. 317; while the snap gauge may be made as shown in Fig. 318. The same general instructions given for making plug gauges and snap gauges apply to limit gauges of the same character.

RECEIVING GAUGE.

When it is essential that the various working points of a tool, part of a machine or apparatus should be in exact relation to one or more given points, a receiving gauge is used. This gauge as the name implies is made to *receive*, or take in, the work; that is, the piece of work is *placed in* the gauge, and the exact location of the different points is determined by the eye.

Fig. 319 shows a gun-hammer, while Fig. 320 represents a receiving gauge for *accurately* gauging the points C, D, E, F, G and H in relation to the fulcrum screw hole A and the face B. These points must also be in exact relation to each other; hence the necessity of a gauge, of this character. When making a gauge of this type, it is customary in most shops to gauge only those parts that must be located in exact relation to some other point or points.

In the case of the gun hammer under consideration the fulcrum-screw hole A must be the main working point because when it is operated it is pivoted at this point, consequently every point must be in exact relation to this hole. The point of next importance is the face B which strikes the firing pin; in order that the face of the hammer may be the proper distance from the firing pin when half cocked, or full cocked, it is necessary that the half cock notch D, and the full cock notch E be properly located as regards the face of the hammer. They must also be in exact location as regards the fulcrum-screw hole A. In-order that the main spring may exert the proper amount of force on the hammer, it is necessary that the spring seat G be exactly located. As the portions marked C and H are intended to just fill the opening in the gun frame when the hammer is in any position, it is necessary that they be located the proper distance from the center of the fulcrum-screw hole A; hence the need of a gauge that will determine the exact location of all points as related to A and B and to each other. As the por-

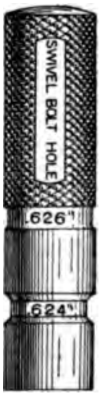


Fig. 317.

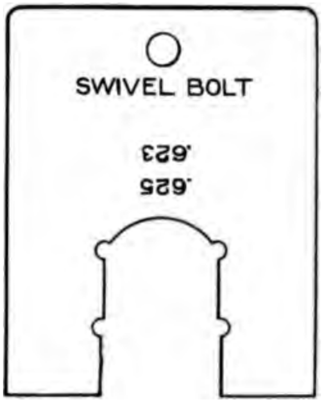


Fig. 318.

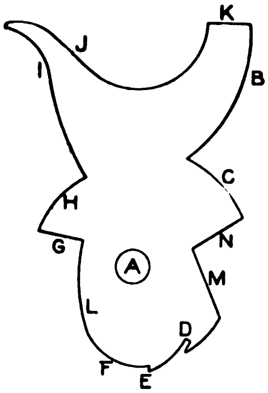


Fig. 319.

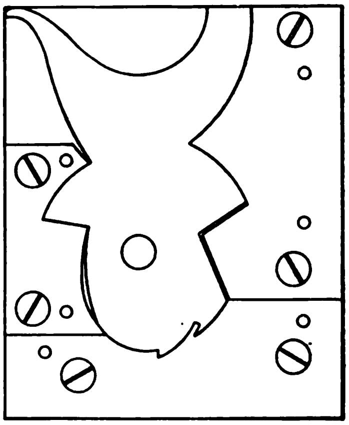


Fig. 320.

tions marked I, J, K, L, M, and N must be in *exact* location to the other points or to each other they are gauged with a ***separate*** gauge because each additional gauging point on a gauge of this description complicates matters.

When making gauges of this character a piece of machinery steel is usually taken for the base; this is planed to size and ground or filed for finish; a hole is drilled and reamed to receive a pin the size of the fulcrum screw hole. This pin is made of a piece of drill rod a few thousandths inch larger than the desired pin. The piece of drill rod should be long enough to be held in the chuck of the grinding machine, and should be cut of the proper length as shown in Fig. 321. The short end should be hardened and the temper drawn to a straw color; after which the wire may be placed in the chuck on the grinding machine and the pin ground to the desired size. After grinding to size it may be broken off and the end ground; this can be done by holding the pin in the chuck, leaving the broken end out in order that it may be ground square, the pin should now be forced to place in the hole in the base.

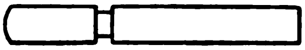


Fig. 321.

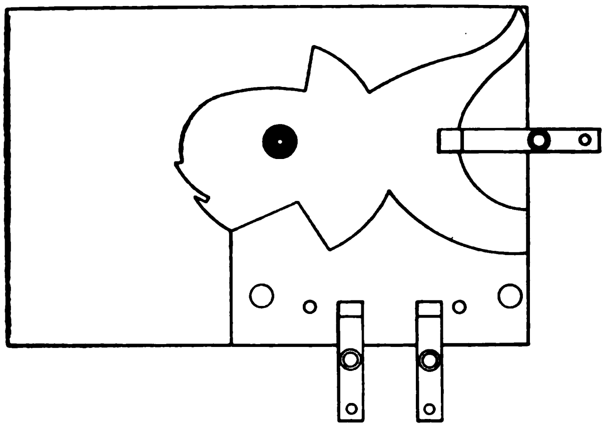


Fig. 322.

The gauge proper may be made of one plate worked to the proper shape, but better results will follow if it is made in three pieces as shown in Fig. 320 on account of the tendency of the plate to spring when hardened.

These plates may be made either of tool steel or machinery steel, if made of tool steel the pieces should be machined all over and thoroughly annealed, after which they may be planed or milled to thickness.

One surface should be colored by the blue vitriol solution, or the pieces may be heated until a distinct blue color appears; the desired shape should be marked on the colored surface and the pieces machined and filed until they fit the model, the necessary degree of accuracy must be determined by the nature of the work.

After the pieces are properly fitted to the model, they may be attached to the base by means of the fillister head cap screws shown. The model should be laid on the base having the fulcrum screw hole on the pin. After arranging the model in its proper location it may be clamped as shown in Fig. 322. The sections of the gauge which should have been previously drilled for the screw and dowel pins, may now be clamped to the base in their proper positions. After drilling, the holes in the base may be tapped, and the screws put in place. If it is found necessary to make slight alterations in any of the shapes, they may be readily made as the plates can be moved a trifle because the bodies of the screws need not fit tightly in the holes in the plates. The dowel pin holes should not be transferred into the base until after the plates are hardened.

The plates may now be removed and hardened. If of machinery steel they may be case-hardened, dipping them in oil rather than water. If made of tool steel best results will follow if the plates are pack-hardened, running them 1 to 1½ hours after red hot and then dipping in raw linseed oil.

If the process of pack-hardening cannot be used, satisfactory results may be obtained if they are carefully heated in a tube in an open fire, or placed in the muffler of a muffler furnace. When red hot, sprinkle a small quantity of finely powdered cyanide of potassium, or a little yellow prussiate of potash on the contact surfaces, place in the fire again, bring to a low red heat and plunge in a bath of oil.

After hardening, the plates may be attached to the base by means of the screws; if any of the gauging points have become distorted by hardening, they may be brought to the proper shape by oil-stoning.

When the plates are properly fitted and located in their exact positions, the dowel pin holes may be transferred into the base and the dowel pins put in place.

LOCATING GAUGE.

This form of gauge is used for determining the location of one or more holes in relation to another hole, a shoulder, or working surface, or any similar measurement.

Fig. 323 shows a gauge for showing the proper location of the hole from the edges A and B, Fig. 324. This gauge consists of a base having four pins for the edges A and B, to rest against. These pins are flatted on the contact edges to prevent wearing. The piece of work to be gauged is placed in position and clamped to the gauge with machinists clamps as shown in Fig. 325. The gauge is fastened to the face plate of the lathe in such a manner that the piece of work can be removed without disturbing the location of the gauge.

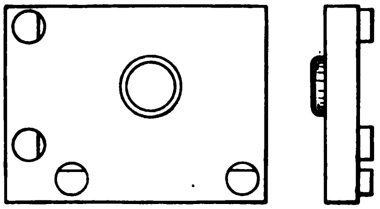


Fig. 323.

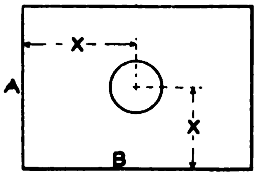


Fig. 324.

A short plug is now inserted in the hole in the model. It is necessary that the plug should fit very accurately. By means of a lathe indicator the gauge can be located so that the plug runs perfectly true. When this has been accomplished the model may be removed and the bushing hole drilled and bored to size; after which the bushing may be made, hardened, ground to size, and forced to place.

The location of the drilled hold be tested by placing the
piece of work on the gauge aga pins, and entering the
gauge pin in the hole in the
326. If the pin is a clo

location may be detected. When a slight error in location is allowable, and it is not considered advisable to hold the location too close, the pin may be made a trifle small, thus transforming the gauge into a limit gauge.

When it is necessary to make a locating gauge for testing the center distance of two holes, one pin may be made removable, while the other is rigidly fixed as shown at C Fig. 327.

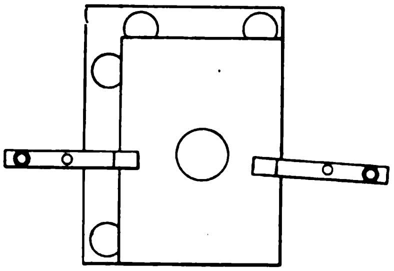


Fig. 325.

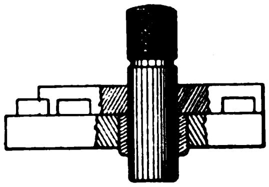


Fig. 326.

If the gauge is made with both pins fixed it is a difficult operation to remove the piece of work, provided the pins are a good fit in the holes. Withdrawing one pin allows the piece of work to be readily taken from the fixed pin.

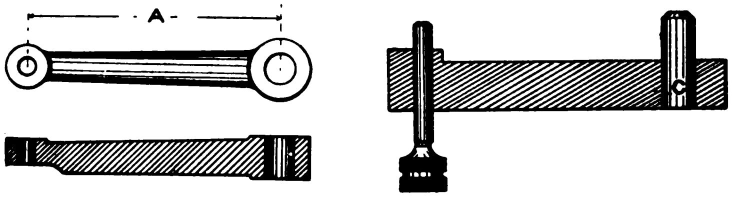
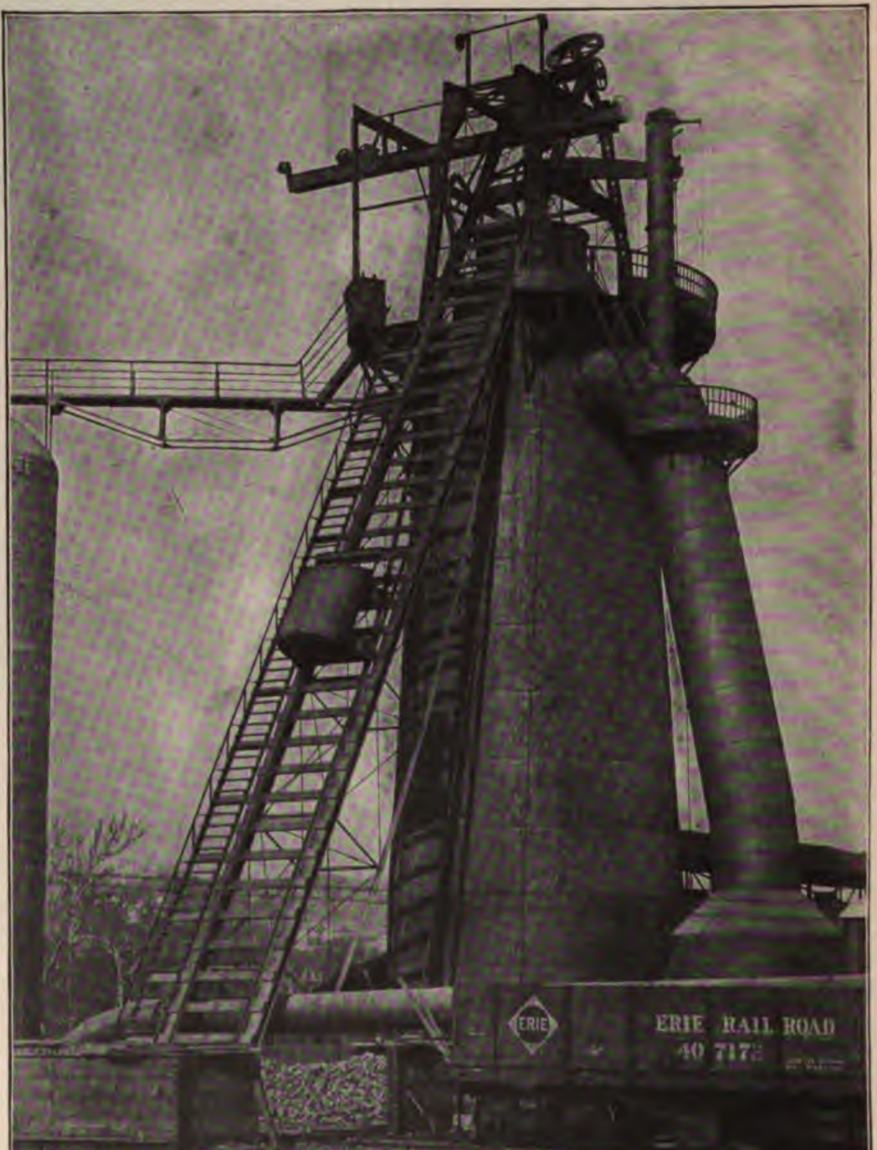


Fig. 327.

When making a gauge of the form shown in Fig. 327, the fixed pin C may be located by approximate measurements; but the hole should be drilled by some method that insures the pin standing perfectly square with the base of the gauge. If a small limit of variation is permissible in the center to center measurement A, the model may be placed on the gauge with the large
ed pin C, and the location of the hole for the mov-
transferred from the model by drilling and ream-

ing. If extreme accuracy is essential, it will be advisable to place the model on the gauge as described, clamp the model to the gauge, then fasten the gauge to the face plate of lathe, place an accurately fitting pin in the small hole in the model, and by means of a lathe indicator locate the gauge so that the pin runs perfectly true. The model may now be removed and the hole drilled and bored to size.



AUTOMATIC FURNACE HOIST
For Feeding Ore and Limestone to Blast Furnaces.

METALLURGY.

IRON.

For centuries iron has been the most useful metal known to man. In the earliest periods of history, stone implements were used; later bronze, an alloy of copper and tin, replaced stone. After a time men found a way to extract iron from its ores, and the Iron Age began. As nothing has yet been discovered, or invented, to take the place of iron in the arts, the Iron Age has continued until the present day. The process of separating, or extracting iron from its ores; of smelting and refining it; and of making it into its most useful form, steel, is called the metallurgy of iron. From small beginnings, this art has gradually increased to its present importance.

ORES.

Iron is never found pure; it is always compounded with other elements or minerals. These compounds, called ores of iron, occur in enormous quantities, and are widely distributed in the earth. The value of an ore depends upon its richness, its locality, the ease with which it can be smelted, and its freedom from phosphorus and sulphur. The principal ores are:

Magnetite, magnetic iron ore (Fe_3O_4). It is black, heavy and crystalline. The finest quality is found in Sweden, and sometimes contains as high as 72 per cent metallic iron. This ore usually contains from 40 per cent to 60 per cent metallic iron. A high temperature is required to reduce it.

Hematite, oxide of iron (Fe_2O_3). A red ore containing about 70 per cent of iron when pure; it is sometimes called "Hard Ore." About 82 per cent of all the ore now mined in the United States is red hematite.

Limonite, or brown hematite ($2Fe_2O_3\ 3H_2O$). Contains r which can be expelled by heat, leaving the ore of a reddish

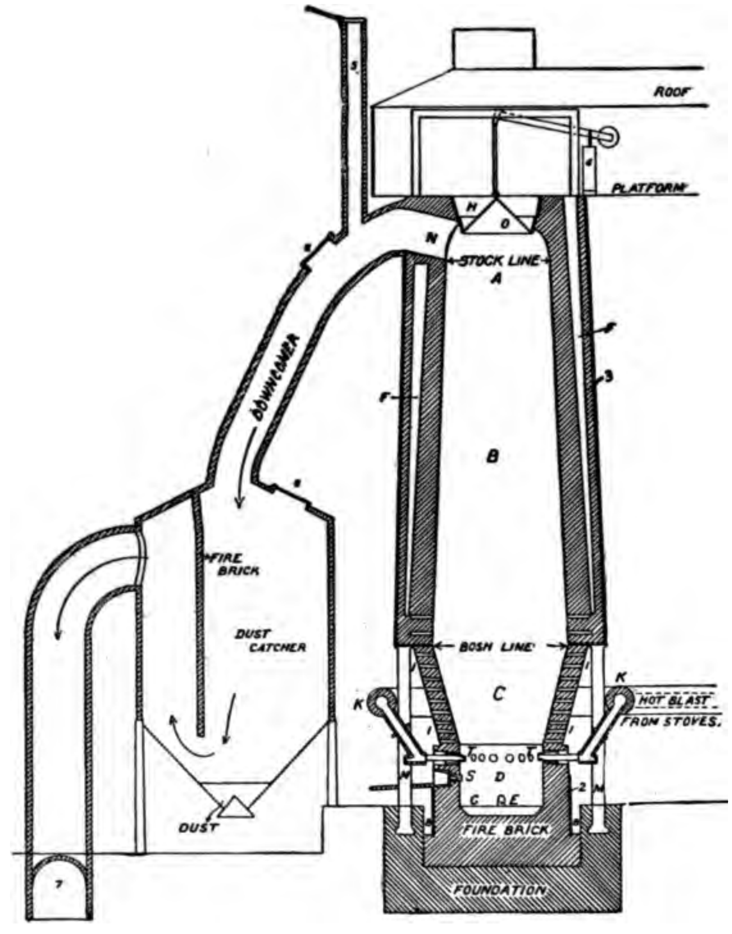
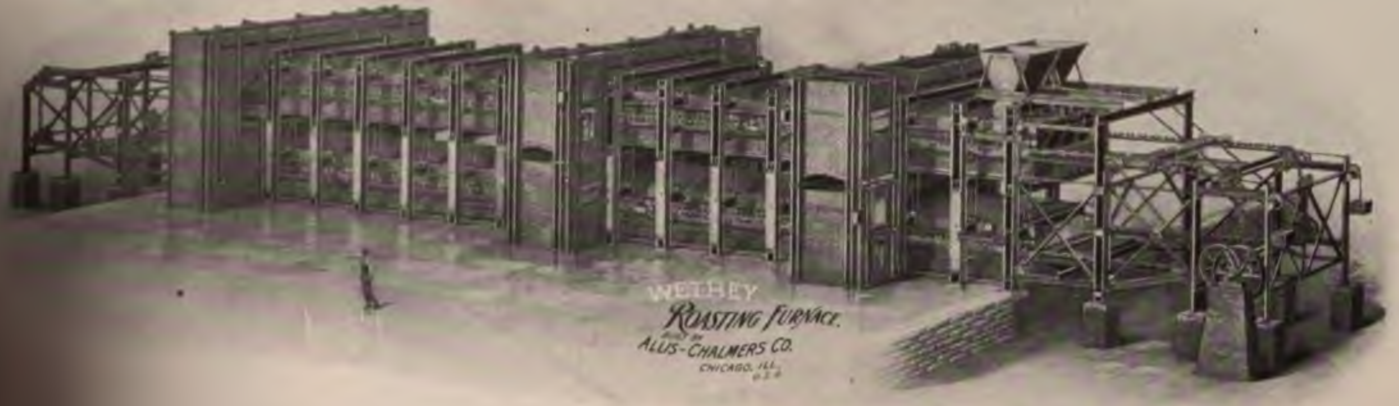


Fig. 1.

1. BRONZE COOLING PLATES.
2. CRUCIBLE JACKET.
3. SHELL.
4. BELL CYLINDER.
5. BLEEDER.
6. EXPLOSION DOORS.
7. FLUE LEADING TO STOVES AND BOILERS.
8. DITCH FOR WATER.

HEIGHT,	90 FEET.
DIAMETER AT BOSH LINE,	20 FEET.
DIAMETER AT CRUCIBLE,	14 FEET.
DIAMETER AT STOCK LINE,	15 FEET.
HEIGHT OF TUYERE CENTER,	8 FEET.
CAPACITY,	400 TONS PER DAY.



WETHLY MECHANICAL ROASTING FURNACE FOR DESULPHURIZING ORES

Length 130 feet, width 12 feet.

color. When pure this ore contains about 60 per cent of iron, and from 8 per cent to 20 per cent of water.

Siderite, or carbonate ($FeCO_3$) or ($FeOCO_2$). This is an important ore in Europe, although containing only about 48 per cent iron. It requires careful preliminary roasting before smelting.

Iron ores are never found pure; they contain varying quantities of silica, alumina, calcium, manganese, sulphur and phosphorus.

MINERALS.

The principal minerals used in iron smelting are:

Iron Pyrites or fool's gold (FeS_2). It occurs in cubic crystals and bright shining scales. This mineral is used as a source of sulphur in the manufacture of sulphuric acid. In some cases it is smelted for iron after its sulphur has been used.

Franklinite, or oxides of iron, manganese and zinc (FeO MnO ZnO) ($Fe_2O_3Mn_2O_3$). It contains about 46 per cent of iron. It is used in the manufacture of zinc white and spiegeleisen. "Spiegel," is a coarsely crystalline variety of cast iron, with large crystal planes having bright reflections. It usually contains about five per cent of combined carbon and 10 per cent to 20 per cent of manganese.

Limestone, *Chalk* or *Oyster Shells*, — carbonate of calcium ($CaCO_3$). Used as a flux.

Dolomite, carbonate of calcium and magnesium [(Ca Mg) CO_3], sometimes substituted for limestone.

PREPARATION OF ORES.

Usually the ore is broken into small pieces and then reduced to metallic iron in the blast furnace. Sometimes it is broken into small pieces, piled up, and exposed to the air and rain. By this means dirt, sand and soft rock are washed out. In this country iron ore is seldom roasted, but when necessary it is roasted in kilns, thus driving out the sulphur.

THE BLAST FURNACE.

The blast furnace is located in a place where materials may
onomically assembled, product cheaply transported to mar-
d a good water supply is available.

The blast furnace is a circular brick or stone structure, lined with fire brick and encased in sheet iron. The general arrangement is shown in Fig. 1. The throat at A is about 15 feet in diameter; the main portion B, called the shaft, is nearly cylindrical and about 60 feet high and 20 feet in diameter. The lower portion C, which is shaped like an inverted frustum of a cone, is called the boshes and is about 20 feet high and 14 feet in diameter in the smallest part. Below the boshes a cylindrical portion D, called the hearth, extends about 10 feet and is lined with fire brick. This total height is about 90 feet, but some are over 100 feet high. The tuyeres T, 6 to 16 in number, are pipes through which hot blasts of air are blown and are built into the brickwork about 6 feet above the bottom of the hearth. The tuyeres are made as simple as possible and constructed so that they may be easily taken out and replaced. The bustle pipe K, supplies air to the tuyeres. The part of the hearth G, below the tuyeres is called the crucible, which being subjected to intense heat, is often cooled by water flowing through a series of open gutters around it. The boshes are kept cool by water circulating through a series of cooling rings, cast in bronze blocks and set in the brick or masonry walls.

There are two openings in the crucible wall; the upper, called the cinder notch for the removal of slag or "cinder," and the lower for the molten cast iron. The upper or "slag eye" S, is stopped up by an iron plug on a long handle; but the lower or "tap hole" E must be plugged with clay. Balls of clay are rammed in and soon baked as hard as stone by the heat. For large furnaces a "gun" is used to force the clay balls into the hole. This clay is two or three feet in thickness and when the iron is ready to flow out it is drilled. The work of drilling through this clay is considerable, and in modern furnaces is done by a steam tapping hole drill.

Just above the throat is the bell O and hopper H (Fig. 1). The materials are placed in the hopper and dumped into the throat of the furnace, by lowering the bell. The bell is raised and lowered by levers and counter-weights, operated by steam or compressed air.

The gases leave the top of the furnace just [illegible] bell at

N; they pass through a dust catcher and then go to the stoves and boilers to be used as fuel. The stoves are used to heat the air for the tuyeres, and the boilers furnish steam for the blowing engines and hoisting engines.

The columns M support the weight of the furnace. The whole rests on the masonry foundation. The space F, called the expansion space, allows for the expansion of the inner wall; it is sometimes packed with granulated slag.

MATERIALS.

The materials used in the blast furnace are:

Ores, already briefly described.

Fluxes. Flux is the substance added to combine with the earthy impurities and make a fusible slag which floats on the molten iron. The impurities which would soon clog up the furnace, are thus removed. Limestone and Dolomite are the usual fluxes. Oyster shells are used in Maryland on account of cheapness.

Fuels. The fuels used are coke, which is made in beehive ovens from soft coal; charcoal, which is wood charred in heaps or kilns; anthracite coal, and very rarely bituminous coal.

The fuel depends largely upon the locality. Charcoal is a good blast furnace fuel on account of its porosity, slight ash, and freedom from sulphur. Coke is the best fuel because it is strong enough to resist being crushed by the great weight of materials and because it burns rapidly thus giving a large output. Anthracite coal breaks up very fine and burns to CO slowly. A good mixture is ¼ coke and ¾ anthracite coal. Bituminous coal is rarely used as it cakes and absorbs heat.

OPERATION OR RUNNING.

Blowing in. To start the blast furnace it is first thoroughly dried and then filled with cord wood to about half-way up the boshes. Upon this is placed a blank charge of coke, and then successive layers of fuel, flux and ore, with gradually increasing amounts of ore, until the regular charge is reached. The wood is then lighted and the hot blast of air turned on. At first this blast is under slight pressure. When coke is used the iron begins to flow in about 15 to 20 hours after lighting.

The ore, fuel and flux are brought to the scales in barrows called buggies. They are then weighed and wheeled to the elevator, and a certain number of barrows of each dumped into the hopper. In many large furnaces self-dumping cars are run to the top on an inclined railway, and the charging is entirely automatic. The fuel charge is usually dropped in by itself, followed by the ore and flux. The level of stock in the furnace is kept constant by regulating the charges. The temperature of the blast is kept as nearly constant as possible, being regulated by the admission of cold air. Cold water is kept running through the cooling rings around the bosh walls. Slag is either drawn off at intervals or continuously, and the molten iron which collects in the crucible, is drawn off every four to six hours by drilling the tap hole. It runs into channels formed in sand; the main channel is called the sow, and the smaller ones branching from it, the pigs. When solid the pigs are broken apart and stacked ready for transportation. The latest development in pig casting is an apparatus consisting of an endless iron mould which revolves and receives the charge and discharges the cooled pigs on the cars.

The furnace is run continuously day and night until it is necessary to shut down for repairs. Sometimes furnaces are run continuously for three to five years.

A good-sized blast furnace using coke as a fuel, will produce 300 tons of pig iron every twenty-four hours, and some of the largest can turn out 600 tons.

BANKING THE FURNACE.

It is sometimes necessary to shut down the furnace, because of a falling market, a flood, or a strike. If it is to be banked at a moment's notice, the first thing to do is to tap out the metal, shut off the blast and the water jackets; then close the furnace so that there will be no draft through the shaft. The tuyeres are blanked by ramming in clay balls. In this case the blast should be resumed in two or three weeks. If there is time to plan the shutting down, a large charge of fuel is dumped in and successive charges containing an increasing proportion of ore. The blast is shut off when the fuel reaches the tuyeres; the bell sealed and the cooling water decreased. The blast need not be resumed in this case for four or five months.

To blow out for repairs, stop the ore charges, and continue to charge fuel with a small amount of flux until the flow of metal ceases.

THE CHEMISTRY OF THE FURNACE.

In the blast furnace the oxides of iron give up their oxygen and become metallic iron. The most important substance for effecting this change is carbon monoxide CO. As we learned in Chemistry, CO gas has an affinity for oxygen, tending to form CO_2.

At the tuyeres the carbon burns to CO. Near the top of the furnace, at a temperature of 400° to 600° F, this CO reduces the iron ore (Fe_2O_3) to metallic iron, thus

$$Fe_2O_3 + 3CO = 2Fe + 3CO_2.$$

The iron is not melted here, but is in a pasty condition. The charge gradually descends, getting hotter and hotter. At the boshes it is at a bright red heat, and in the lower part the iron begins to melt, and the lime, silica and other earthy materials fuse and form slag. At this point part of the silicon, manganese, sulphur and phosphorus are reduced, and together with a little carbon, combine with the iron. In the crucible all is melted and the temperature is above 2200° F.

SLAG.

The earthy materials, silica, alumina, and sulphur of the ore and fuel, combine with the flux, and form the slag. A large part of the sulphur is then eliminated from the ore; but none of the phosphorus. The quality of the iron depends largely on the composition of the slag. If a high lime slag is used in order to reduce the sulphur and silicon in the pig iron, there is danger that the slag may not run well, in which case more alumina is used. A good slag has approximately the following constituents: 52 per cent CaO + MgO, 16 per cent Al_2O_3 and 32 per cent SiO_2.

STOVES.

In the first blast furnaces cold air was used for the blast. s were introduced to effect a saving of fuel and to increase ut-put. The waste gases from the blast furnace contain 5 per cent of carbon monoxide, CO, and 1 per cent of hydrogen, H. These gases are burned with air in brick stoves and the fire brick flues are heated to redness. Then the cold air blast is run through and is heated to above 1000°F.

Four stoves are generally used in a set, three being heated while the fourth is giving out heat to the blast. The fuel consumption with a hot blast is about one-half that with a cold blast.

CAST IRON.

The iron produced by a blast furnace, known as cast iron or pig iron, is impure. It contains carbon, phosphorus, sulphur, silicon, manganese, and traces of other elements.

Cast iron is brittle, fusible and cannot be welded. It melts at a temperature of 2100°F. to 2300°F. Gray iron is more fluid when melted, and not as brittle as white iron.

Cast iron is suitable for castings because it expands at the moment of solidifying; this expansion is due to the change in the position of the crystals and results in a sharp impression of the mould. The casting is smaller than its pattern because the shrinkage in cooling from a red hot solid is greater than the expansion at the moment of solidification. If iron moulds are used, the surface of the casting becomes chilled, which causes a harder surface.

The Tensile Strength of cast iron is 13,000 — 29,000 pounds per square inch; Compressive Strength 82,000 — 145,000 pounds per square inch; Modulus of Elasticity 14,000,000 to 22,000,000.

Pig Iron is sometimes graded according to its fracture. This method is satisfactory if the irons are made from uniform ores and mixture of fuels; but is unreliable if the irons are produced in different sections of the country, or from different ores. Grading by chemical analysis is better. There are five standard grades according to hardness.

No. 1. Gray. Fracture rough. It is dark, open grain and the softest grade. Used exclusively in foundry work. Tensile Strength low. Elastic Limit low. Turns soft and tough.

No. 2. Gray. Mixed grain. Harder than No. 1. Fracture less rough, with higher Tensile Strength and Elastic Limit than No. 1. Used in foundry. Turns harder, less tough and more brittle than No. 1.

No. 3. Gray. Close grain. Used in foundry and rolling mill. Turns harder and less tough than No. 2.

No. 4. Mottled. Dotted with small black dots of graphite. Little

grain. Used in rolling mill. Lower Tensile Strength and Elastic Limit than No. 3.

No. 5. White, no grain, smooth fracture. Used in the Bessemer process and in the rolling mill. Tensile Strength and Elastic Limit lower than No. 4. Too hard to turn and very brittle.

The following table gives average analyses of the various grades of cast iron, the amounts being given as per cents:

Grade Number.	Iron.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
1	92.37	3.52	.13	2.44	1.25	.02	.28
2	92.31	2.99	.37	2.52	1.08	.02	.72
3	94.66	2.50	1.52	.72	.26	Trace	.34
4	94.48	2.02	1.98	.56	.19	.08	.67
5	94.68	——	3.83	.41	.04	.02	.98

INFLUENCE OF CARBON, SILICON, PHOSPHORUS, SULPHUR AND MANGANESE.

Carbon. The state of the carbon in the pig iron is a most important factor in the quality. If the carbon is combined with the iron in the form of an alloy, a hard, brittle, white iron is produced. If it is present mainly as graphite distributed as small crystals throughout the entire mass, the iron is soft and gray in color, but not as strong as white iron. Gray iron expands more on solidifying and contracts less in cooling than white iron.

Silicon. The amount of silicon and the rate of cooling determine the proportion of graphitic to combined carbon in the casting. Increasing the silicon in cast iron increases the proportion of graphitic carbon, thus making the iron softer. A large quantity of silicon renders the iron stiff and weak.

Phosphorus. Phosphorus in general weakens cast iron, but it is not harmful if less than 1 per cent is present. In some cases phosphorus is beneficial, as it decreases shrinkage and increases fluidity. For small, thin castings, iron may contain a little over 1 per cent phosphorus.

Sulphur. Sulphur makes castings hard and unsound. It also prevents the iron from flowing well. The amount of sulphur should not be over .5 per cent for sharp castings.

Manganese. Manganese in cast iron increases hardness and shrinkage and makes it more brittle. Manganese makes the iron capable of holding more carbon. Sometimes the amount of carbon is as high as 5 per cent, as in Spiegel.

Manganese with some chill is used in the foundry to produce hardness of surface. The magnetism of iron is decreased by manganese ; if 25 per cent is present all magnetism is lost.

CASTINGS.

In order to get a good casting, an iron having the following requisites should be used :

Shows gray fracture.
Is easily worked by tools.
Fills the mould to the thinnest parts.
Chills with a smooth surface.
Free from blow-holes.
Has moderate strength.
Little shrinkage.

An iron with the following constituents fills these conditions:

Carbon,	3½ per cent.
Silicon,	1½ per cent to 2 per cent.
Phosphorus,	not over .7 per cent.
Sulphur,	only a trace.
Manganese,	.35 per cent to .70 per cent.

For large castings lower the silicon. For increase in strength lower the carbon, silicon and avoid phosphorus. For resistance to chemical action make the manganese as high as brittleness will allow.

Silver-gray and ferro-silicon irons are used to increase silicon. Spiegel and ferro-manganese are used to increase manganese. Both wrought iron and steel scrap are used to reduce carbon.

MALLEABLE CAST IRON.

Malleable cast iron is a crude form of wrought iron obtained by decarbonization. The castings are made in the ordinary way from low silicon iron with little phosphorus and sulphur ; they are embedded in oxide of iron or peroxide of manganese and heated to a red heat until most of the carbon is removed from the surface. The time necessary for this operation is three to fourteen days, depending upon the size of the casting.

An analysis for good malleable iron is:

Si	.75 — 1.00 per cent.	P	.20 per cent.
S	below .05 per cent.	Mn	.40 to .75 per cent.

This wil be a No. 3 iron.

In making malleable castings, sharp angles and abrupt changes from heavy to light sections should be avoided. Several thin ribs in place of one thick rib should be used. As much surface as possible should be exposed, as the strength lies in the skin.

WROUGHT IRON.

Removing most of the carbon, silicon, phosphorus and manganese from pig iron makes it tough, malleable, harder to melt and capable of being welded. This iron is known as wrought iron, and is obtained by a process called puddling. The operation of making wrought iron from the ore is called a Direct Process. On account of its simplicity it was the first used.

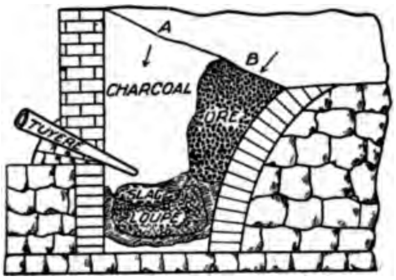


Fig. 2.

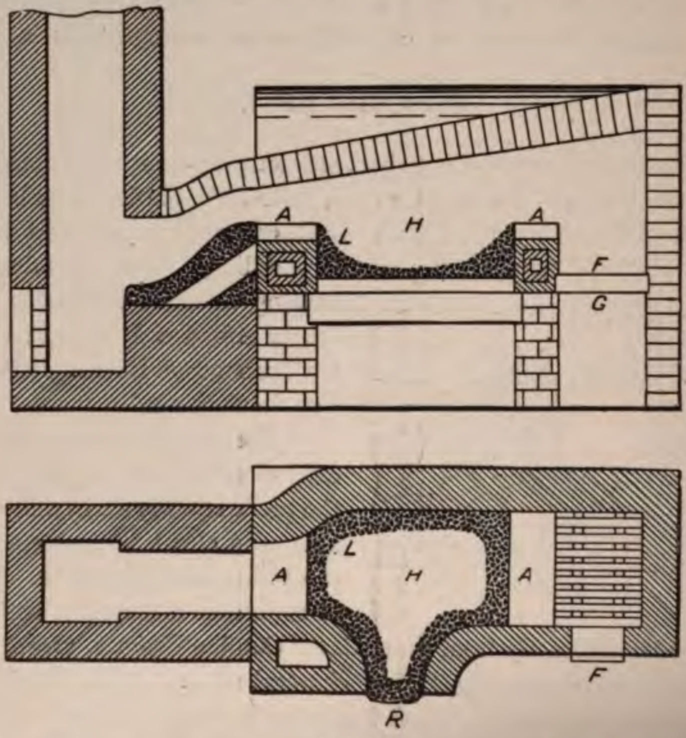
The Direct Processes are carried on at a low temperature; the production is small and variable, and about 20 per cent of the iron in the ore is lost. One of the oldest methods of making wrought iron directly from the ore is the Catalan Process. Ore of egg size is charged at B, Fig. 2, and charcoal at A. As the smelting progresses, charcoal and moist fine ore are charged at A. As the ore becomes reduced it works towards the tuyere; when it is all reduced it is taken out in a large lump called the "loupe" and worked under a hammer.

There are other processes, but they are unimportant and most all have been abandoned.

THE PUDDLING PROCESS.

The refining of pig iron by puddling converts it into wrought iron. This process is carried on in a reverberatory furnace. Fig. 3 shows sectional view of the plan and elevation.

The furnace has a low-arched roof and oval hearth H. The flame from the fire passes over the charge of iron, which is melted by the intense heat. The pig iron used in this process is gray and unrefined and has more silicon than white iron. The fettling or lining L of the hearth is made of good magnetite or hematite. The fettling is repaired after every heat.



A. — BRIDGES.
F. — FIRE-DOOR.

Fig. 3.

G. — GRATE.
R. — RABBING-DOOR.

Carbon, silicon, manganese, phosphorus and sulphur unite with oxygen from the hot blast and the iron ore lining, thus reducing the molten metal to wrought iron. In order that the whole of the metal may come in contact with the fettling it is stirred constantly by rods called "rabbles." It [illegible] minutes to melt down, and then carbon b[illegible]

CO gas, which makes a violent boiling for about 15 minutes. The silicon, manganese, etc., oxidize and form a slag. When all the carbon is boiled out, bright points appear and the iron becomes pasty. The iron is gathered into balls and then worked under the hammer and rolls to expel the slag. It is afterward reheated and rolled between grooved rollers, which causes the particles to become close together. If the bar is rolled once it is called muck bar; if cut up, heated and rolled again, merchant bar; the best bar iron is rolled a third time.

The Puddling Process and the manufacture of wrought iron is gradually giving way to mild steels; but because of the small amount of slag it contains between the fibres, which acts as a flux, wrought iron welds much easier than steel and is preferred by blacksmiths.

The Puddling Process is expensive on account of the large amount of fuel used in the production of metal. About one ton of fuel is necessary to produce one ton of muck bar. For this reason and on account of the expense of the mechanical work of puddling, many efforts have been made to produce a cheaper and more simple process.

Boilers have been mounted over the furnace to utilize the waste gases as fuel, but on account of the fluctuating heat of the furnaces they have not been entirely successful. Water-tube boilers mounted in this way have been the most satisfactory.

There are several contrivances to save fuel and labor, but as the mechanism is likely to get out of order, they are not always reliable. For saving of labor, the Dank's Puddling Furnace, Fig. 4, is the most efficient and satisfactory of the mechanical puddlers. It is shaped like a short barrel, lying on its side. It is supported by friction rollers, two at each end, and driven by a large gear G around its middle. In this furnace the revolving of the hearth takes the place of puddling or stirring by hand.

Iron ore worked in layers at low heat forms the fettling. It is fed with molten iron from a furnace by means of a ladle. In some places this furnace is used for ordinary puddling, and in others for making wrought iron for the Open-hearth and Siemens Processes for making steel.

Wrought iron contains from .5 per cent carbon to only a trace; as carbon decreases, malleability increases, and the melting point rises. The melting point of good wrought iron is about 3000°F.

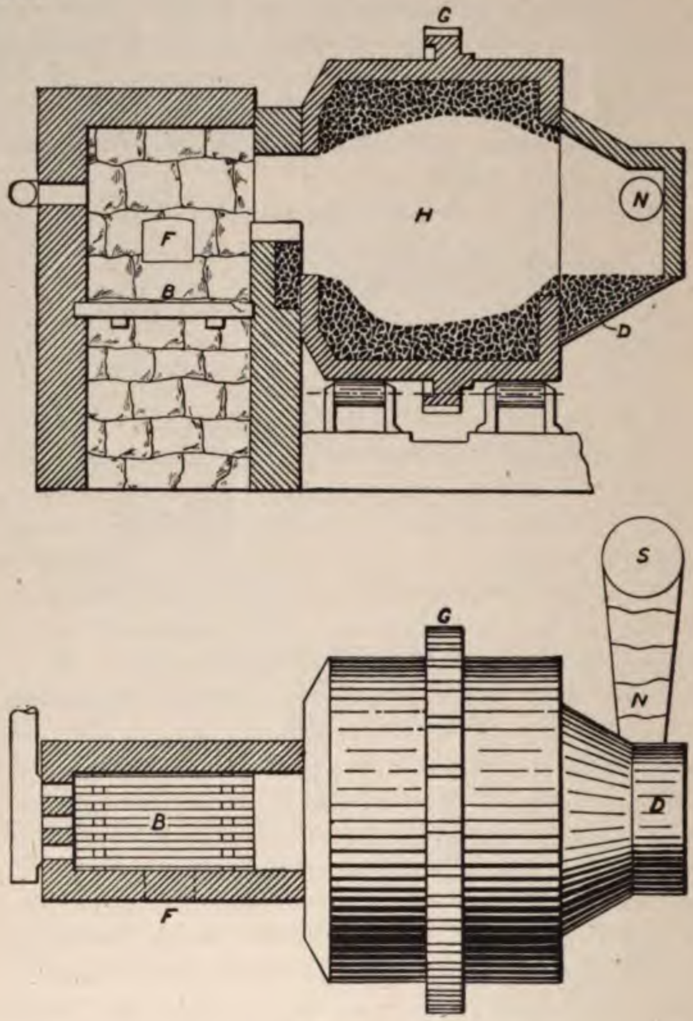


Fig. 4.

B—GRATE.
F—FIRE-DOOR.
H—HEARTH.
D—MOVABLE FLUE-PIECE.
N—FLUE TO STACK.
S—STACK.

Wrought iron contains about 2 per cent of slag distributed among the fibres. It is always present because the iron is finished in a pasty condition and the slag is never completely removed by the subsequent squeezing and rolling.

The fracture of wrought iron is coarsely fibrous, sometimes showing a few bright granular spots. The best iron is granular when broken suddenly.

The reduction of area of bars by rolling influences the strength and elastic limit. In general, the greater the reduction the higher the strength and elastic limit. Underheated bars have an unduly high tenacity and elastic limit.

The absolute strength of wrought iron is not materially altered by cold. The extensibility, or ductility, is not less in severe cold than at ordinary temperature. The modulus of elasticity rises as the temperature falls.

WELDING.

The process of welding consists of heating two pieces of iron to a high temperature, laying them together and hammering. Borax is sometimes sprinkled on the surfaces to be united, in order to keep them bright. This is accomplished by the union of borax with the oxide forming a fusible borate. In order that the form of the piece after welding may not be spoiled by hammering, the two ends to be joined are upset and scarfed. The upsetting makes the ends larger, so that they may be hammered without making the joint too small, and the scarfing roughens the ends, making the pieces join more easily.

STEEL.

CEMENTATION PROCESS.

Cement or blister steel is made from wrought iron by this simple process. The purest, soft wrought iron is heated to redness while completely covered with charcoal. The temperature is kept constant for over a week. The iron takes up some of the carbon from the charcoal and is converted into steel. It is called blister steel on account of its appearance, the surface being covered with small scales or blisters. These bars of blister steel are cut, heated and rolled together, forming shear steel. If the process is repeated, the product is called double shear steel.

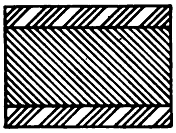
Blister steel that has been cut up, melted in a black-lead pot and cast in an ingot, is called cast or crucible steel.

The metal used in Sheffield, England, is wrought iron made from Swedish pig iron. Hammered wrought iron bars are laid in firestone pots in layers, surrounded with charcoal. At one end is placed a test bar, so arranged that it may be drawn out, examined, and returned. The temperature is gradually increased for 7 days to about 1150° F., and then the furnace is kept at this temperature for 7 or 8 days more. It takes 7 days for it to cool down.

When the bars are taken from the charcoal, the outside layers are converted into steel, leaving the center wrought iron. The use for which this steel is intended determines the amount of conversion; the various kinds are classified as follows:

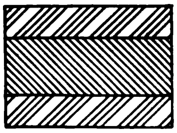
(1) Spring heat, .5 per cent C. Large iron center.

1



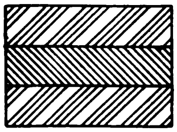
(2) Country heat, .63 per cent C. Smaller iron center.

2



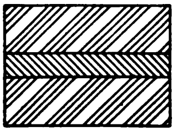
(3) Single shear heat, .75 per cent C. Equal iron and steel.

3



(4) Double shear heat, 1 per cent C. Mostly steel.

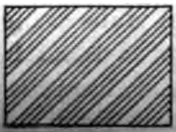
4



(5) Steel through heat, 1.25 per cent C. All steel.

(6) Melting heat, 1.5 per cent C. All steel.

5 AND 6



The reaction which

$4Fe + 2CO$

CRUCIBLE PROCESS.

The materials are bar iron with charcoal, puddled bar or blister steel and charcoal. The crucibles are made of clay or graphite, with a capacity of 50 to 85 pounds. The charge is put into the crucible, and after melting is allowed to stand for a time, called the killing period, and then poured into moulds.

In American practice, graphite crucibles are used, which are made from a mixture of fire-clay and sand, and about 50 per cent graphite. This mixture is ground, allowed to stand for a few days, and is then moulded by being pressed into a wooden mould. When dry, it is baked in a kiln. These crucibles can be used about five times, if the successive charges are gradually diminished in amount.

The crucible is charged cold. The pieces of iron are surrounded with charcoal, with a little manganese, and sometimes a little salt or ferrocyanide of potassium mixed with it. This crucible, after being covered, is placed standing on the coal in a hot furnace. After three hours, during which the contents are melted, the cover is lifted, and the melter examines the charge to determine the length of the "killing" period. During this period, which is about 45 minutes, the metal is becoming tranquil and is taking silicon from the sand in the walls of the crucible. The silicon prevents blow-holes. At the right time and temperature the crucible is lifted out and the slag skimmed off. The metal is now ready for casting, or "teeming." This is done by pouring the metal into split moulds.

The ingots are graded and hammered into bars for different uses. Crucible steel furnishes the finest grades for cutlery and machine tools; it is superior to Bessemer and Open-hearth steel, because pure materials are used and the process is carried on in a closed vessel, thus protecting the metal from sulphur gases from the fuel.

It has low phosphorus, low sulphur, no iron oxide, less gases, high carbon and high silicon.

Crucible steels are graded as follows :

r. 1½ per cent C. Easily burned, very hard temper, welded with

a. 1⅜ per cent C. Not easily burned, hard temper.

Tool. 1¼ per cent C. Not easily burned, hard temper, welded with difficulty.

Spindle. 1⅛ per cent C. Not easily burned, hard temper, welded with difficulty.

Chisel. 1 per cent C. Not easily burned, fair temper.

Set. ⅞ per cent C. Difficult to burn, little temper, easy to weld.

Die. ¾ per cent C. Difficult to burn, little temper, easy to weld.

THE BESSEMER PROCESS.

Bessemer, by his experiments, found that the temperature of molten metal was raised by blowing a current of air through it.

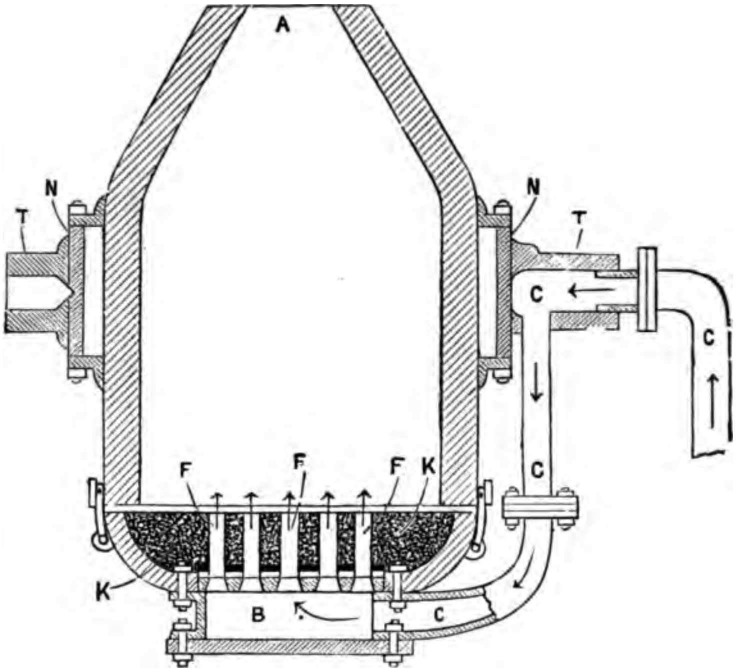


Fig. 5.

He tried to make wrought iron from pig iron, but found that the metal taken from the converter at that point was worthless; by restoring carbon by means of an alloy the product was better than wrought iron.

By this process steel is made from pig iron by burning out the foreign substances and replacing the necessary amounts of carbon, and manganese. These foreign substances — silicon, car-

DOUBLE ENGLISH CUPELLING FURNACE.

Allis-Chalmers Co.

bon and manganese — are burned out by blowing a blast of cold air through the molten pig. The desired amounts of carbon and manganese are replaced by mixing the proper proportion of spiegel with the molten pig.

The process is carried on, not in a furnace but in a vessel called a converter, in which molten pig is "converted" into steel.

There are several forms of converters. Fig. 5 shows a concentric converter. It is round, with a detachable flat bottom. The outer casing is of sheet iron. It is filled and emptied at the nose A. The current of cold air enters through the pipe C, and passes through the trunnion T. It enters the converter from the wind-box B, passing through the tuyeres F. The tuyeres are of fire brick 24 to 28 inches long, and have 19 holes $\frac{5}{16}$ inch in diameter, or 7 holes $\frac{3}{8}$ inch in diameter. The trunnion rings N are fastened to the converter, which turns on the trunnions T. The bottom is coupled on with clamps.

The pig iron is not melted in the converter, but poured into it in a molten state.

There are two processes of working.

(1.) The Acid Bessemer.

(2.) The Basic Bessemer, or Thomas-Gilchrist.

The difference is in the lining of the converter. If this lining is acid (siliceous) no phosphorus or sulphur is burned out of the pig. Only irons with small amounts of these elements can be used in this process. If the lining is of lime or magnesia all the phosphorus and almost all of the sulphur can be burned out. Only a high phosphorus pig can be used in the basic process, as the heat needed to keep the steel liquid, during casting, is obtained from the phosphorus.

The Basic Process is used in Germany with good results.

In both processes the carbon, silicon, manganese, etc., are oxidized, leaving the molten iron in a condition similar to that of wrought iron. The carbon passes away as CO, and the oxides of silicon and manganese with a little iron oxide form a slag. Molten spiegel is added to give it the necessary carbon, and a little manganese to make it malleable. The molten pig is obtained in two ways; by melting the pig in cupolas, called the Cupola Process; and by taking the iron from the blast furnace, called the Direct Process.

THE CUPOLA PROCESS.

Pig iron, from piles which have been sampled and analyzed, is loaded into trucks and wheeled to the cupolas. The composition of this mixture is about as follows:

Silicon	1.75 per cent.
Manganese	.75 per cent.
Sulphur less than	.05 per cent.
Phosphorus less than	.10 per cent.
Copper less than	.10 per cent.

This is weighed, hoisted to the cupola and dumped in. Spiegel is sampled, analyzed and melted down in smaller cupolas. The fires in the cupola are started with wood upon which is placed coke; the charges of pig iron being dumped on the coke. It takes about two hours to melt the first charge. As some silicon burns out in the cupola the percentage is reduced. When the iron goes into the converter there must be from 1 to 2 per cent silicon present, depending on the temperature of the iron.

THE DIRECT PROCESS.

In the ordinary blast furnace, different casts differ too much in silicon and sulphur to allow taking the metal as it flows from the furnaces into the ladle and then to the converter. Therefore, it is first poured into large reservoirs or mixers, in which the casts from the different furnaces are mixed. In Sweden, however, the product from a number of small charcoal furnaces is regular enough for the iron to be used directly. The iron is taken from the mixers as wanted and used as cupola iron. If the iron stands in the mixer a long time some sulphur is eliminated, but no carbon or silicon. To prevent the iron from chilling on top, a jet of oil is sprayed over it. As the temperature of direct iron is greater than that of cupola iron, less silicon is needed.

Blowing. The heated bottom is coupled on and the joint rammed tight from the outside. When the lining is made yellow-hot by means of a fire of wood and coal with a gentle blast, the iron from the cupola or the mixer is poured in and the blast turned on.

The converter is turned up to a vertical position, as shown in Fig. 6, as it is filled when turned down on its side. The blast rushes up through the bath, and silicon begins to oxidize raising the temperature high enough for the carbon to burn. Carbon burns to CO. The blower judges whether there will be enough heat to keep the steel liquid during the casting, by the appearance of the flame which comes out of the throat of the converter. If he thinks there will not be enough heat, the converter is turned half-way down and the CO burns to CO_2. Fig. 7 shows the converter turned down until the tuyeres are exposed.

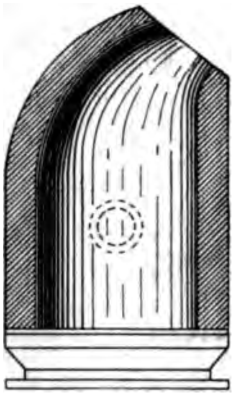


Fig. 6.

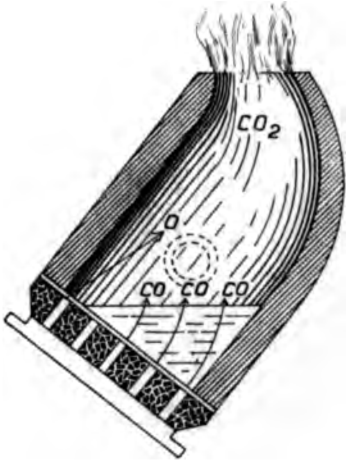


Fig. 7.

In case there is too much silicon for good working, or if the charge is too hot, cold steel scrap is dropped into the nose of the converter from a platform above. The scrap, being free from silicon, reduces the percentage of silicon in the converter. If the steel is made too hot it will not roll well. Sometimes a jet of steam is admitted to the blast pipe to cool down a charge. The carbon is reduced to about .05 per cent after about 12 minutes blowing under a pressure of 30 pounds per square inch. This is shown by a shorter flame. An instant later the flame becomes fringed with brown smoke which is Fe_2O_3. The converter is now ready for the spiegel. The spiegel contains about 20 per cent manganese and 4.5 per cent carbon. If hard steel is being made, spiegel is used, but if it is to be soft, which requires some manganese and but little carbon, ferro-manganese is used instead of spiegel. This has 80 per cent manganese and 6.5 per cent carbon. The amount of molten spiegel added is about 10 per cent of the weight of the converter charge, and of ferro-manganese from 1 per cent to .8 per cent. The ferro-manganese is not remelted but shoveled red hot in pieces the size of an egg into the casting ladle. After the steel has been poured out into the ladle most of the slag remains in the converter. It is dumped into a car beneath by tipping the converter bottom up. This loss or waste is from 10 per cent to 12 per cent.

The charge varies from 5 tons in a small converter to 20 tons in a large one, and a new charge is blown every twenty minutes. The bottoms of the converters are examined and any bad tuyeres are plugged with plumbago mud and blanked. The life of one of these bottoms varies from 18 to 25 "blows." The conditions which injure the bottom are low blast, a great depth of metal above the tuyeres, too much Al_2O_3 and Fe_2O_3 in the ganister mixture, and dampness of the repairing material. The bottoms are dried four days in a drying oven; several of these are always kept on hand drying, for if not absolutely dry, they are useless.

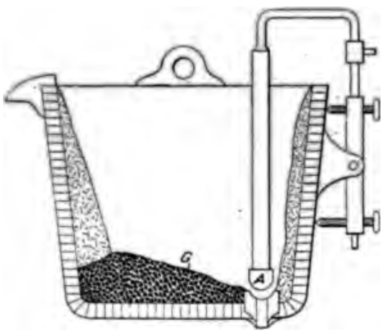


Fig. 8.

"Acid" Converter Lining. Converters are lined with blocks of ganister with the joints faced with ganister mud. If pure ganister is used it is likely to give trouble on account of its expansion under heat. Too much Al_2O_3 causes the lining to melt out rapidly. The bottom is lined with a mixture of ground ganister and fire clay. Ganister, a flinty sandstone, is composed of about 98 per cent of SiO_2 with about 1 per cent or 2 per cent of $Fe_2O_3 + Al_2O_3$. The fire clay has about 86 per cent of SiO_2, 10 per cent Al_2O_3 and 4 per cent of alkalies. If the manganese in the pig iron is less than 1½ per cent the linings last for months. A high lime slag in the pig will rapidly flux the SiO_2 of the lining. The nose section is lined with brick or stone and lasts but a short time.

The Casting Ladle. The general shape and arrangement of the casting ladle is shown in Fig. 8. The shell is made of iron plate and is lined with a layer of brick and upon this is pounded moist loam. The bottom G is made of rammed ganister material. The pouring hole is fitted with a cylindrical brick nozzle, with a hole 2 to 4 inches in diameter. The stopper A sets upon a bowl shaped seat. The stopper and stopper slide are shown in the figure. The end of this stopper, which fits the seat, is made of plumbago. The lining of the casting ladle lasts about 40 blows. A new nozzle and stopper is put in about every fourth blow.

Moulds. The moulds must be hard enough to withstand the strain caused by expansion and contraction when heated or cooled, yet not brittle. These moulds, if made of iron, have a composition as follows:

Silicon	1.7 per cent
Phosphorus	.1 per cent
Manganese	.75 per cent

Moulds are made of gray iron as white iron is too brittle. These moulds last about 90 operations.

INGOTS.

Method of Pouring. Great care is necessary in the pouring of ingots. They should be poured in such a manner as to prevent spattering, oxidation of the surface and injury to the mould. There are three principal methods: Top pouring, the most natural, bottom pouring, and a combination of top and bottom pouring. The greatest objection to ordinary top pouring is that of spattering and oxidation of the surface. These are partly overcome by the admission of the molten metal through a pipe which reaches nearly to the bottom of the mould. By mechanical means, this pipe slowly recedes, so that the distance between its end and the surface of the metal is nearly constant. If the mould is bottom poured, the metal at the bottom, being kept hot, has a tendency to thin the bottom and walls of the mould. If they become too thin they are likely to crack or burst. The slag has to rise through the entire column of metal and if this becomes cooled particles of slag become entangled. Also, the slag has a tendency to solidify in the pipe by which the metal is introduced, thus causing poor ingots. The best results have been obtained from a combination of top and bottom pouring. During the first half of the time the metal is bottom poured and then finished by top pouring. In this case, the gases and slag have only a short distance to rise.

Shape of Ingots. Ingots are usually square with rounded corners slightly tapered to one end, so that they may be easily removed from the mould.

Gases and slag rise to the top of the ingot. Sometimes a "pipe" is formed in the center by the metal solidifying and shrinking away from the center. To prevent this the top is kept liquid longer by a covering of sand. It is advantageous to keep the cavity near the top, so that a large portion of the ingot will be sound. Another method is to cast ingots one on top of the other in a column, pouring one as soon as the preceding one has begun to solidify. This brings the cavity and imperfections in the last ingot. Another remedy is to cast the ingots longer than is necessary and cut off the top; but this is a waste of metal for the cut off portion has to be remelted and recast. Another way is to make the top rounding, in order to allow the impurities and gases to collect in the rounded part.

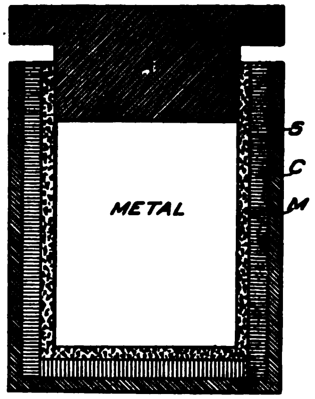


Fig. 9.

We learn from Chemistry that the solubility of gases in liquids increases with pressure; this principle is made use of in the casting of ingots. The mould is arranged as in the accompanying diagram, Fig. 9. The outside S is formed of steel in which is a thin layer C of perforated cast iron, the mould being lined with moulding sand M. The top plunger A is stationary. The mould is made to rise by powerful machinery. When the metal has begun to solidify the mould is raised until the pressure becomes 10 to 20 tons per square inch; this pressure is kept on for about 20 minutes. The gases are not squeezed out by this process; the pressure tends to dissolve them. This process is used in making armour plate and gun tubes, but is too expensive for ordinary use.

Rail Making. Very soon after an ingot is poured it commences to solidify at the surface. A solid shell forms with a pasty or liquid interior. As the ingot cannot be rolled until it has become of uniform softness it is put in a "soaking pit." By means of currents of hot gases, the ingot soaks or equalizes, that is, it becomes uniform throughout. It soaks in these hot gases for about an hour. The ingot is taken from the soaking pit by an electric traveller, and is rolled down in the blooming mill to a "bloom" of about 7 inches by 7 inches in section, which, after the ragged edges have been cut off by hydraulic or steam shears, is finished, without re-heating, in a rail mill. Sometimes the bloom is allowed to partially cool and is then reheated before being finished. This process is expensive on account of the fuel and labor, but it reduces the number of defective rails. The whole ingot is rolled in the rail mill into one long rail, and this is cut into standard lengths by hot saws. After the rails cool they are straightened in steam presses and are then inspected and bolt holes drilled in the ends. Steel rails have the following composition:

Carbon,	.40 per cent to .6 per cent
Phosphorus,	.08 per cent to .1 per cent
Manganese,	.75 per cent to .9 per cent
Sulphur,	.05 per cent to .1 per cent
Silicon,	.05 per cent to .15 per cent
and sometimes Copper,	.01 per cent to .2 per cent

If the carbon is above .6 per cent the rail will be too brittle and will break under the drop test. In this test a heavy weight is allowed to fall through a specified distance on a piece of rail about 3 feet long, supported at the ends.

If the carbon is below .4 per cent the rail is too soft to stand
r of the car wheels; if the phosphorous is above .1 per
teel will be "cold short" (brittle); if the manganese is
r .75 per cent the ingot will crack in rolling; if the

sulphur is above .1 per cent there will be short feathery cracks in the ingot when rolled, especially if rolled at a low red heat. Silicon up to .15 per cent improves the rolling qualities of the steel, but makes the steel brittle if the percentage of silicon is much higher.

The Bessemer process is also used in making soft steel. This steel is made into barbed wire, wire nails, hoop iron and sheets for tin plate and galvanized iron; it is also used for some structural steels and agricultural implements. This steel has about .1 per cent to .15 per cent carbon, and .4 per cent to .5 per cent manganese.

About 70 per cent of the steel made in the United States is Bessemer steel, and about 30 per cent of this is made into rails.

THE OPEN HEARTH PROCESS.

The Open Hearth Process for making steel is divided into three methods, according to the character of the material used. They are,

1, The Martin Process, in which pig iron and scrap are used.

2, The Siemens Process, or "pig and ore" in which pig iron and ore are used.

3, The Combination Process, using pig iron, scrap and iron ore.

The open hearth process was made possible by the invention by Siemens of the regenerative chambers, first successfully used by Martin, and is often called the Siemens and Martin process. The fuel is gas, which is burned on the hearth of a large reverberatory furnace. Both the gas and air are heated by the products of combustion in the regenerative chambers, as represented by Fig. 10. The heated gas and air enter the furnace on the left, burn on hearth H, and the products of combustion pass out and down through the chambers A and G on the right. These chambers are filled with fire brick set up with spaces between, called checker work, which becomes heated to a white heat. After a time the currents of gas a [illegible] reversed and pass through the checker work i [illegible] heated before they combine and [illegible]

The currents are [illegible] ur)

and a very intense heat is maintained so that the metal in the condition of wrought iron is kept in a molten state.

In this country the combination process is generally used. With this process the scrap and pig iron are first melted. As this iron contains too much carbon, iron ore is added to reduce the percentage. This process, like the Bessemer, has two main divisions, the Acid and the Basic open-hearth processes, having siliceous and lime-magnesia linings respectively, and like the Bessemer process, only low phosphorous iron can be used with the acid lining while high phosphorous stock is used with the lime lining. In the Bessemer process only medium and low carbon steels can be made, while in the open-hearth, steel of any grade of carbon can be made. This process also has the advantage of being more under control, and the product is more uniform, more reliable and contains less gas. Open-hearth steel costs about $2.00 a ton more than Bessemer.

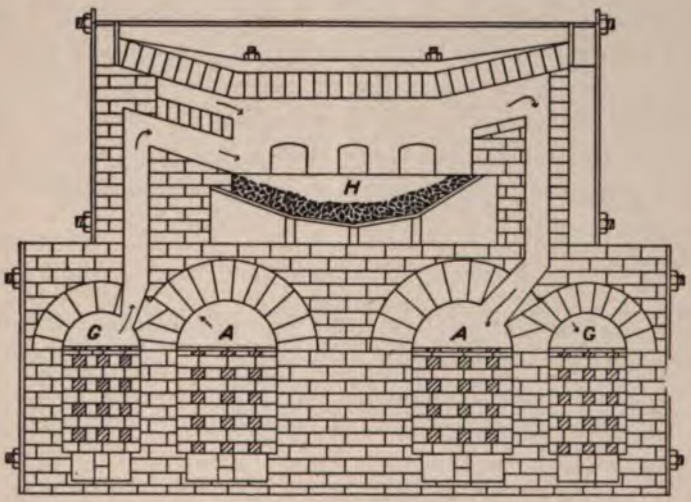


Fig. 10.

Open-hearth steel is used for making spring steel (carbon .8 per cent to 1 per cent) for cars and wagons; structural steel for bridges and buildings; steel for agricultural implements and tools; cast steel and mild steel (low carbon) for boiler plates (carbon .15 per cent, and phosphorus .03 per cent).

The Bessemer process and open-hearth process can be advantageously carried on together, as the scrap and "crop ends" of the Bessemer are largely used in the open-hearth.

MANAGEMENT, OR RUNNING THE ACID PROCESS.

At the start the furnace is heated by a wood fire, and then the gas is turned on and lighted. When the temperature is sufficiently high to melt steel, the charge is put in. It consists of one-third pig iron, and the rest wrought iron and steel scrap. On account of the low melting point of pig iron, one-half of the pig iron is put in first on the bottom. If steel or wrought iron were charged first, it would be slow in melting. The scrap is then put on and covered by the rest of the pig, and currents of air and gas are reversed at intervals, each time coming up hotter. In four hours it is all melted, but the carbon is too high, and it is not yet ready for casting. To expel this carbon small amounts of iron ore are added. CO is produced, which boils off.

$$Fe_2O_3 + 3C = 3CO + 2Fe.$$

This boiling continues until the desired percentage of carbon is reached, which is determined by sampling. These samples are taken out at intervals, cooled and broken ; the percentage of carbon being judged by the appearance of the fracture. As the boiling down occupies three or four hours, there is time for an approximate chemical analysis. Manganese and silicon have both been absorbed by the slag, therefore some manganese must be added before casting. This is done by adding to the casting-ladle red-hot spiegel, or ferro-manganese, the size of peas. If steel castings are being made, a little silicon must also be added, to prevent blow-holes. When the steel is ready chemically, it is usually hot enough to cast. The furnace is tapped by driving a bar through the tap-hole, and the molten metal flows out of it into the casting-ladle, which is similar to that of the Bessemer process. The casting is done in moulds, as in the Bessemer process. Bottom pouring is often employed, especially if the ingot is to be made into steel plate. The bottom of the mould has to be repaired after each operation.

MANAGEMENT OR RUNNING THE BASIC PROCESS.

The furnace used is very similar to that of the acid process, except for the lining, which is of dolomite or magnesite. Dolomite is hard-burned lime made from a magnesia limestone. Magnesite is made from $MgCO_3$, calcined several times at high heat. Layers of dolomite or magnesite, mixed with 10 per cent of boiled tar, is rammed in with hot rammers all over the bottom and sides, above the slag line. Upon this hearth, scrap and high phosphorous pig iron are melted down. To prevent fluxing of the lime lining, limestone is spread over the bottom before charging. After melting there is too much phosphorus and carbon in the charge. These elements are oxidized by the addition of the iron ore. The agitation and boiling of the phosphoric bath is caused by the escaping gas, CO, and the metal is thus brought in contact with the basic slag and the phosphorus removed. If all the phosphorus is not out at this point, pig iron is added to raise the percentage of the carbon, and the bath is again boiled down. The appearance of the fracture of the sample indicates the amount of phosphorus present. If there is a large amount, two cross-lines of bright crystals, called the "Phosphorus Cross," appear in the center. The casting is the same as in the Bessemer process. The wear of the basic lining is greater than that of the acid, especially if the silicon is high. Holes in the hearth are repaired after each heat.

The tap-hole is rammed with tar dolomite or magnesite.

In an ordinary open-hearth furnace only two heats can be made in a day. The charge varies from 10 tons in a small furnace to 50 tons in a large one.

Tilting furnaces are being used in modern plants, which lessen the time of charging and working, and "direct metal" from mixers is used in place of pig, which further reduces the time. Altogether, the open-hearth process is gaining in favor in this country., The basic process is more used than the acid, because high phosphorous pig is cheaper.

GAS PRODUCERS.

Gas is the fuel used in the open-hearth process. The Siemens Gas Producer is now little used, most gas being made by the

Wellman Gas Producer. Fig. 11 is the sectional view of this producer. A forced draft, usually a steam-jet injector, supplies steam and air to the furnace under slight pressure. The following reactions take place when air or steam unite with coal:

$$\begin{aligned} C + O_2 &= CO_2 \\ CO_2 + C &= 2\,CO \\ H_2O + C &= CO + 2\,H \end{aligned}$$

The resulting producer gas has about the following composition:

Nitrogen,	60.3 per cent
Carbon Monoxide,	22.8 per cent
Carbon Dioxide,	5.2 per cent
Oxygen,	0.4 per cent
Hydrogen,	8.5 per cent
Hydrocarbons,	2.8 per cent

In running the producer, there is a heat loss of about 35 per cent, principally in radiation, ashes, latent heat, decomposition of steam, and sensible heat of gas. Another producer, the Taylor Producer, has in place of the grate-bars a revolving dome-shaped plate, through which air is driven into the center of the fire. In place of the brick lining this producer has a water-jacket. Bituminous coal is the fuel generally used in these producers. As this gas contains about 60 per cent nitrogen, it is weak fuel. In a few localities natural gas, a stronger fuel, is obtained. A gas made of vaporized petroleum mixed with dry steam and forced through a red-hot metallic retort, is used in the Archer process.

SPECIAL STEELS.

Nickel Steel. Nickel steel is made by adding metallic nickel, nickel ore, or ferro-nickel, to the bath of the open-hearth process. The nickel increases its density, elasticity and strength. This steel is used for armour plate, on account of these qualities, and also because it does not corrode. Nickel steel contains about 4 per cent nickel, .3 per cent carbon, .7 per cent manganese, and .02 per cent phosphorus. For such uses as bicycle tubes, shafts, axles, etc., the high elastic limit of nickel steel tends to prolong indefinitely the life of the piece, and because of its superior toughness, offers greater resistance to sudden strains and shocks.

Aluminum Steel. From .05 per cent to .1 per cent aluminum in steel castings reduces the melting point, prevents blowholes, and keeps the metal liquid while being poured. Aluminum gives no increase of hardness.

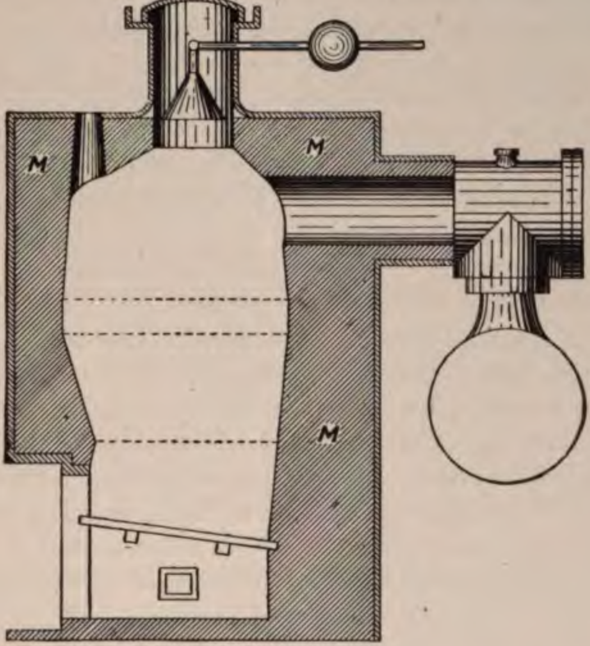


Fig. 11.

Chrome Steel. If chromite is melted in brasque crucibles with charcoal, the result, ferro-chrome, which has 40 per cent chrome and 48 per cent iron, is used in making chrome steel, by melting it with bar iron in crucibles. Chrome, like manganese, hardens iron. It also makes it more forgeable. It is used, on account of its hardness, for burglar-proof safes, but it is not entirely satisfactory, and other steels are fast driving it out. It has about the following composition: chromium, .5 per cent to 3 per cent; carbon, .5 per cent to .9 per cent.

Manganese Steel. Manganese steel is an alloy of iron and manganese, containing a considerable proportion of carbon. It there is a very small portion of manganese, the effect is slight. As the proportion of manganese rises above 2.5 per cent the strength and ductility diminish, while the hardness increases. This hardening effect is a maximum with about 6 per cent manganese. Above this the strength and ductility both increase, and at 14 per cent of manganese the metal is so hard that it is difficult to cut with steel tools. It welds with great difficulty, but it can be forged. Its toughness increases by quenching from a yellow heat. It has a remarkable combination of great hardness, which cannot be lessened by annealing, great tensile strength, toughness and ductility. The fact that it cannot be machined, on account of its hardness, limits its usefulness. It is used principally for car-wheels, dies and crusher-jaws.

Tungsten Steel. Steel containing a little carbon and tungsten is much harder than steel with carbon alone, and yet not very brittle. A specimen from Sheffield, England, for chisels, used untempered to turn chilled rolls, was not brittle, yet it was hard enough to scratch glass. It contained 9.3 per cent tungsten, .7 per cent silver and .6 per cent carbon. In working this metal it has to be given its final shape by hammering at red heat, and if the percentage of tungsten is high it is necessary to reheat it while it is being hammered. After the desired shape is reached the hammering must be continued, with numerous blows, until it becomes nearly cold. Tungsten is employed to produce steel of moderate hardness, with great toughness, resistance and ductility. Its principal use is for cutting-tools. It is self-hardening.

CASE-HARDENING.

By the process called case-hardening, a thin layer of steel is formed over the iron. To do this, iron is heated to redness, and powdered potassic ferro-cyanide $K_4Fe(CN)_6$, is sprinkled over the surface. When suddenly cooled, the surface of the iron is hard enough to resist a file. The chemical reaction which takes place is

$$K_4Fe(CN)_6 = 4KCN + FeC_2 + N_2.$$

THE HARVEY PROCESS.

The Harvey process for making armor plate is somewhat like case-hardening. The outside of the heated steel plate is covered with charcoal, from which it absorbs carbon in the same manner as wrought iron absorbs carbon in making cement steel. The layer of hard steel thus formed is further hardened by quenching with water. This makes a plate with an exceedingly hard surface, which breaks up shot and shell. The backing is, however, tough, mild steel.

THE EFFECTS OF THE ELEMENTS IN STEEL.

The following from Howes' Metallurgy of Steel will give an idea of the effects of the elements:

Carbon. Carbon up to 1.5 per cent increases Tensile Strength, Compressive Strength, and raises the Elastic Limit; decreases the malleability and welding power.

Silicon. Silicon increases hardness, Tensile Strength and solidity, and prevents blow-holes. Too much silicon makes steel brittle. From .3 per cent to .5 per cent should be the maximum.

Sulphur. Sulphur causes hot shortness; that is, the metal is brittle when hot, both under the hammer and rolls.

Arsenic has the same effects as sulphur.

Phosphorus causes cold shortness. It makes steel hard and liable to break. It increases the Elastic Limit and reduces Elongation.

Manganese prevents hot shortness and blow-holes, removes or offsets the effect of sulphur. It increases Toughness, Elongation and Tensile Strength. Too much manganese makes steel brittle when cold, especially after quenching.

Copper. Copper causes red shortness; .5 per cent may be allowed in rails, but 2 per cent makes steel worthless. Tin steels are not forgeable or ductile, either hot or cold.

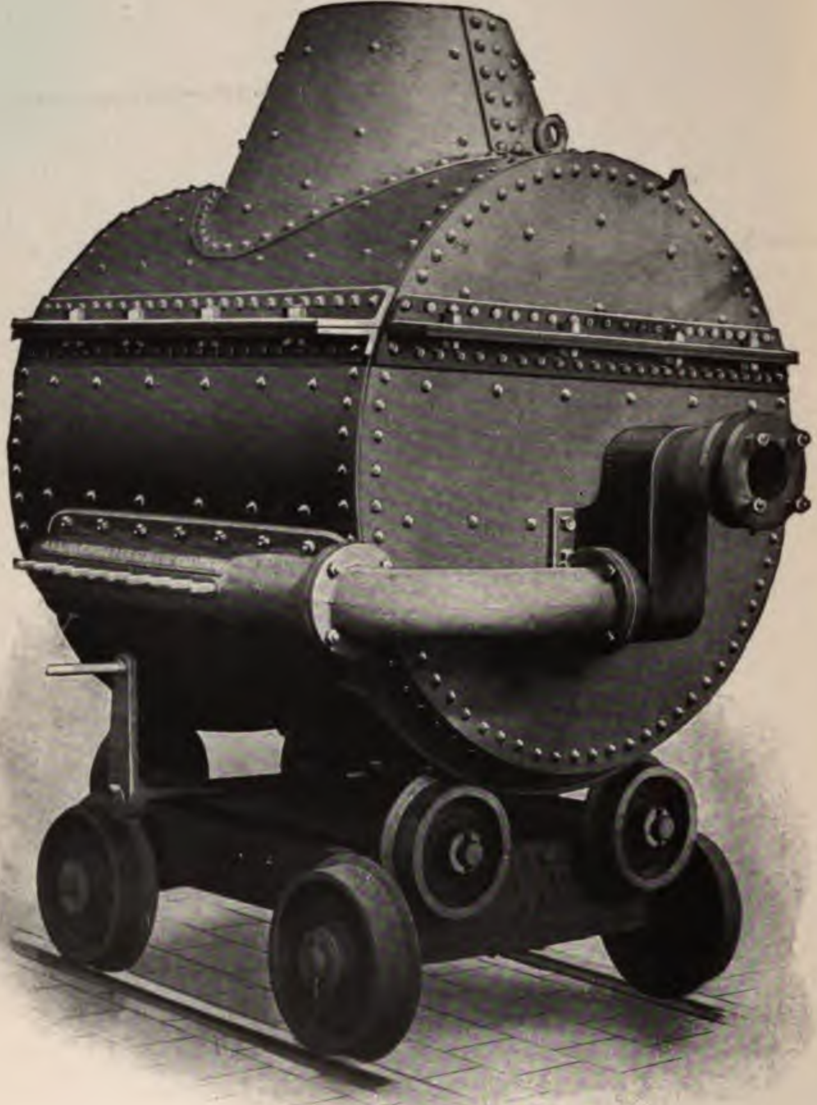
TEMPERING.

Tempering steel is the process of giving it, after it has been shaped, the necessary hardness to do its work. A piece of steel after it has been properly tempered should be finer in grain than the bar from which it was made.

This is accomplished by first hardening the piece, usually harder than necessary, and then toughening it by slowly heating and gradually softening, until it is just right for the work. The process is as follows: The tool to be tempered is heated to a cherry red, and plunged into cold water or oil to a depth somewhat above the cutting edge. When this portion has become entirely cold, the piece is taken out and the cold end polished, usually with emery-cloth; the point is now too hard and brittle. The heat contained in the hot portion gradually enters by conductivity into the quenched part, and as it does so, colors are formed which denote temperature. The colors seen in order are pale yellow, straw, brownish yellow, light purple, dark purple, blue. They are formed by oxide on the surface. These colors run from the hot portion to the cutting edge, and when the proper color reaches the cutting edge, the whole piece is quenched. Some tools are of such a shape that the temper must be "drawn" to the desired color by reheating the piece between hot plates or in a hot iron ring.

The following list will give some idea of the colors, temperature and hardness of tools:

Very pale Yellow, temperature about 430° F.	Steel-engraving Tools. Turning Tools. Hammer Faces. Planer Tools. Wood-engraving Tools.
Straw Yellow, temperature about 460° F.	Dies. Taps. Drills. Punches. Reamers.
Brown Yellow, temperature about 500° F.	Gouges. Plane Irons. Twist Drills. Cooper Tools. Wood-boring Cutters.
Light Purple, temperature about 530° F.	Augers. Surgical Instruments. Cold Chisels. Edging Cutters.
Dark Purple, temperature about 550° F.	Axes. Gimlets. Needles. Hack Saws. Screwdrivers. Springs. [illegible]



SMALL CYLINDRICAL CONVERTER. For Copper Matte.
Allis-Chalmers Co.

COPPER.

As copper occurs in the metallic state, it was one of the earliest known metals. The native copper deposits of the Lake Superior region were worked by prehistoric inhabitants. Copper compounded with tin was the metal of the Bronze Age. With the exception of iron, copper is our most useful and important metal.

ORES.

The native copper of Lake Superior is still an important source of supply, but by far the largest quantity is obtained from the sulphide ores, of which Copper Pyrites ($Cu_2 S. Fe_2 S_3$) is the most important. When pure it contains 34.6 per cent of copper, 30.57 per cent iron and 34.9 per cent sulphur, but the average ore carries only about 12 per cent of copper. Spanish iron pyrites is another source of supply; it is first used in the manufacture of sulphuric acid, after which the copper is extracted from the "cinder." It contains only 3 or 4 per cent of copper, but carries also a small proportion of gold and silver, which makes it a profitable ore.

Carbonate ores, formed by the weathering of the sulphides are now about exhausted, as they occur only a short distance below the surface.

EXTRACTION.

There are two main processes for extracting copper from its ores:

(1) Process involving fusion.

(2) Wet process used for low-grade ores.

The most important fusion method is the "Welch" or "Reaction" process. The prepared sulphide ore is first roasted in heaps, kilns or a reverberatory furnace. Care is taken that not too much of the sulphur is expelled. Next, this calcined ore is fused in a reverberatory furnace. The copper has a greater affinity for the remaining sulphur than any of the other metals, and copper sulphide is formed.

$$Cu_2O + FeS = Cu_2S + FeO.$$

The ferrous oxide (FeO) and the silica unite and form a slag, which carries away lime or other impurities present. The cuprous sulphide Cu_2S combines with the excess of iron sulphide left in the charge, forming a fusible substance called a "regulus," or first copper matte, which contains about 30 per cent of copper. This first matte is again roasted and fused, and part of the iron slagged away as before, leaving the second matte, which contains about 50 per cent, if "blue metal" is wanted, or 75 per cent of copper, if "white metal" is being made. A small amount of metallic copper is also produced. These copper bottoms contain most of the impurities, including much of the gold and silver.

In a third reverberatory furnace the second matte is again partly oxidized and then fused, the product this time being crude metallic copper and a slag rich in copper. The rich slags from the first and second matte are worked up for their copper. The reactions by which metallic copper is produced are:

(1) $2Cu_2O + Cu_2S = 6Cu + SO_2$

(2) $3Cu_2O + FeS = 6Cu + FeO + SO_2$

The SO_2 gas passes away and the FeO goes into the slag.

Producer gas is used for heating the furnaces in modern plants.

CUPOLA SMELTING.

In the first stages of this process the chemical action is about the same as the "Welch" method. A first and second "Matte" is produced in small water-jacketed blast furnaces of rectangular sections using cold blast. (See Fig. 12.) Some "black copper" is produced with the second matte.

The second matte, called "white metal," is now completely roasted to oxide. This oxide of copper is reduced to metallic copper in a blast furnace by CO gas in the same manner as in the production of iron.

The reaction is

$$Cu_2O + CO = 2Cu + CO_2$$

The fuel is coke or charcoal. The slag from the first matte is thrown away, but the other slags go back into the process.

Less skilled labor is necessary in the cupola method and less fuel is required. It is consequently in favor in remote regions. The metal of oxidized ores (carbonates) can be extracted by this process in one operation. The reverberatory method produces purer copper, and must be used when there is much antimony and arsenic in the ore. Highly refractory ores, which are difficult to fuse in a blast furnace, can be better treated in reverberatories, as the slag can be skimmed off in a partly melted condition.

The variations in the foregoing processes are numerous. A common American practice is to use the cupola for obtaining the first matte, and finish the process in reverberatory furnaces.

Modified Bessemer converters are now successfully used to convert copper matte into crude copper. The converter has the tuyeres in the sides, and is lined with silica and clay. As the wear on the lining is very great, provision is made for quickly replacing a worn-out converter by one which has been relined. Mattes containing from 30 to 60 per cent copper have been thus successfully treated at a considerable saving of expense.

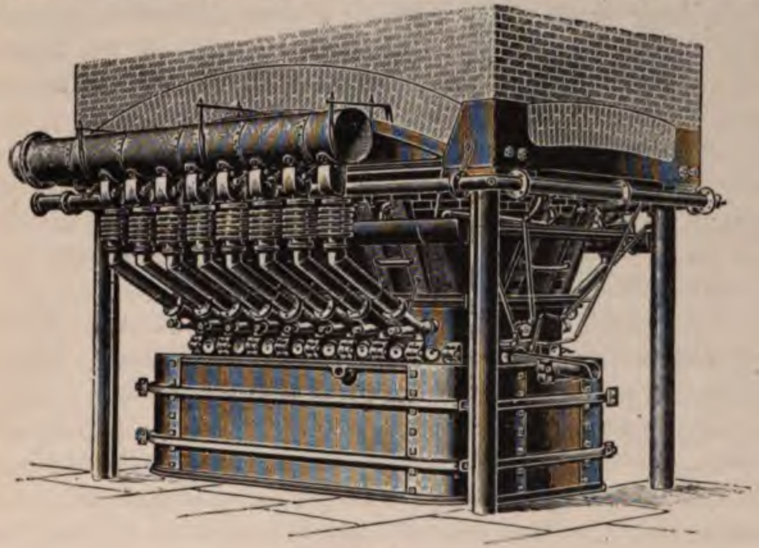


Fig. 12.

REFINING.

The crude copper produced by any of the foregoing methods is refined in a reverberatory furnace with a large hearth. It is slowly melted down with an excess of air. The impurities oxidize first and form a slag with the silica from the lining of the [illegible]s slag is frequently skimmed off. The copper [illegible] oxidize, forming Cu_2O, which acts on any Cu_2S, forming SO_2, which causes the molten metal to boil. When this action ceases, the copper contains too much copper oxide. This is reduced by "poling." Poles of green wood are thrust into the bath, and the distilled hydrocarbon gases cause the bath to boil, which expels any SO_2 gas remaining. Charcoal is spread over the molten metal, which, with the hydrocarbon gas, removes the oxygen from the Cu_2O, leaving metallic copper. Samples are taken out from time to time, and when the color changes from red to flesh color, and the sample becomes fibrous with silky lustre and can be bent double, the refining is finished. The rich slags go back into the process. A little oxide of copper is left in the metal, as it neutralizes the effect of the small amount of remaining impurities.

The metal is then run into small moulds. An ingot "under poled," containing too much oxide, will show a furrow along its surface. An ingot with the right proportion will have a flat surface, called "tough pitch," and one which is "over poled," containing too little oxide, will show a ridge.

Electric refining is fast replacing this older method. In the United States two-thirds of the product is thus refined. By the electrical method all the gold and silver in the copper is recovered, and the copper produced is very pure. The crude copper is cast into slabs as it runs from the furnace. A row of slabs is placed in a tank containing a solution of copper sulphate made acid with sulphuric acid. These form the dissolving plates, and opposite each is placed a thin sheet of pure copper. The tanks are connected in series by wires and the current passed through. The electric current causes the crude copper to dissolve and pure copper to be deposited on the thin plates. The gold and silver, together with other impurities, fall to the bottom as mud or "slimes," from which the precious metals are extracted by chemical processes.

The *wet process* is used for lean ores. It has the advantage of extracting at the same time any gold and silver present. This process involves getting the copper and precious metals into sol[illegible]tion either as sulphate or chloride and then the copper is [illegible]tated by electrolysis, metallic iron or quicklime.

The solutions are produced either by dissol acids or roasting the sulphide to sulphate or by roasting with salt to obtain the chloride and then leaching with water.

PROPERTIES OF COPPER.

Copper is a rather soft metal and is very ductile and malleable. It can be worked both hot and cold, but should not be heated too hot, as it crystallizes and takes up oxygen. When worked cold it is stronger and harder, but less ductile. Heating and quenching make it softer. Rolled sheet copper has a tensile strength of from 24,000 to 28,000 pounds per square inch, and annealed wire over 40,000 pounds per square inch. Good castings cannot be made from pure copper because they contain blowholes and the shrinkage is too great.

Copper is not affected by the weather, but in damp places it is slowly corroded; carbonate of copper, called verdigris, being formed by the carbonic acid of the air.

The thermal conductivity of copper is high.

The electrical conductivity of good copper is but little less than that of silver, and is about six times that of iron. A very small amount of impurity reduces its electrical conductivity as much as 10 per cent. Antimony is the most harmful impurity from a mechanical standpoint, and should not be over .02 per cent.

The growth of electrical industries has greatly increased the demand and price of copper of late years. It is estimated that 60 per cent of the world's production of copper is consumed in electrical work. The United States produces over 55 per cent of the world's output of copper, or over a quarter of a million long tons annually.

LEAD.

The most important ore of lead is Galena, lead sulphide (PbS). In the United States it is found in the upper valleys of the Mississippi and Missouri Rivers and in the Rocky Mountains. The mines of Spain, Germany and England furnish the bulk of the European product. It occurs in bright, shining, cubic crystals of metallic lustre. When pure it contains 86.6 per cent of lead. Galena usually contains silver, and frequently a small amount of gold. It is associated with sulphides of zinc, antimony, copper and iron. As it is a very heavy mineral it is easily concentrated.

Cerussite — lead carbonate, $PbCO_3$, — is an ore of some importance and is mined in Leadville, Colorado.

SMELTING.

Lead ore is smelted either in reverberatory furnaces or blast furnaces. When using the reverberatory furnace with sulphide ore, the chemical action whereby lead is produced is much the same as in the final stage of copper smelting in the "Welch" method. The ore is partially oxidized to lead oxide, PbO, at a low heat, some sulphate, $PbSO_4$, also being formed. Then the temperature is raised and the lead is produced according to the following reactions:

(1) $PbS + 2PbO = 3Pb + SO_2$

(2) $PbS + PbSO_4 = 2Pb + 2SO_2$

The lead as it is formed runs into a pot, and the operation is repeated until no more lead can be extracted, when it is tapped and the slag withdrawn in a pasty condition. This "gray slag" is usually smelted in a blast furnace for the lead it still contains. This method is simple and the apparatus inexpensive, but its use is limited to high-grade ores containing 60 per cent to 70 per cent of lead, and only 4 or 5 per cent silica. The process requires much fuel and skilled labor.

SMELTING IN A CUPOLA OR BLAST FURNACE.

This process is used for all ores containing over 4 per cent silica, for carbonate ores, and for various lead slags and drosses obtained in purifying the crude lead.

The Furnace is built of brick and lined with fire brick. It is usually oblong in section. The shaft is from 14 to 20 feet high and tapers downward to the boshes, which taper more sharply to the crucible. The section at the crucible is usually about 12 feet by 3 feet 6 inches. The tuyeres, 6 or 8 in number, are placed on each side, near the top of the crucible. The boshes and part of the crucible are cooled by cast or wrought iron water jackets. The furnace is charged through a door in the side, near the top.

As lead is somewhat volatile, provision must always be made for collecting the lead fumes. Various devices have been tried, but long flues, wherein the fumes condense and settle, are most commonly used. The top of the furnace is connected with one of these flues.

The sulphide ores are roasted in a reverberatory furnace or in hand or mechanical kilns. The roasted ore is charged into the blast furnace with suitable fluxes and various mixtures of coke, charcoal and coal as fuel. Iron plays an important part in the smelting, as it is capable of decomposing silicate of lead and is added as an iron slag or as ore if not present in correct amount.

In smelting there is usually a small amount of matte formed, consisting of sulphides of iron, copper, nickel and lead. This is tapped with the slag into a slag pot, where it rises to the top and is separated when the mass cools. The matte is broken up and roasted and its lead and copper recovered. The lead collects in the crucible and is tapped out at intervals.

SOFTENING AND DESILVERIZING.

The lead obtained by either the reverberatory or blast furnace method contains copper, arsenic, antimony and other metals in addition to silver. The impure lead is slowly melted down in a reverberatory furnace. The lead, having a lower melting point than the impurities, liquefies first, leaving a residue containing the copper and part of the arsenic and antimony. The lead is next heated very hot with an excess of air, and then most of the remaining impurities oxidize and form a scum, which is skimmed off. The silver remains with the softened lead and is extracted by the Park's Process. This process depends upon the fact that a small percentage of zinc added to the molten lead will collect all the gold and silver to form an alloy, which, being of less specific gravity, rises to the top, and having a higher melting point solidifies before the lead.

From the softening furnace the molten lead is run directly into a large kettle. Here from 1 to 3 per cent of zinc is added to three successive portions. After each addition the mass is well stirred and then allowed to cool somewhat, when a crust is formed, which is removed. The first crust contains most of the gold and is called the gold crust. The second crust is called the silver crust, and the third crust, containing the silver that still remains, is used for the first addition to the next charge.

RECOVERY OF THE SILVER AND GOLD.

The gold and silver crusts are melted slowly in a kettle or reverberatory furnace, and most of the lead mixed with the crust melts out and is recovered. The zinc is distilled off in large graphite retorts, leaving a small amount of lead, which contains all of the silver and gold. The lead is separated from the precious metals by cupelling. In the cupelling furnace the lead is oxidized to litharge (PbO), leaving the metallic silver and gold. The furnace has a hearth made of porous material, which absorbs part of the melted litharge as it forms; the remainder runs into a pot. The litharge is ground and sold if it does not contain too much silver, in which case it is smelted again. About 60 per cent of zinc is recovered in metallic form and is used again in the desilverizing kettle.

REFINING THE DESILVERIZED LEAD.

The desilverized lead contains .6 per cent to .7 per cent of zinc, which is removed in a reverberatory furnace or large kettle. The charge is heated very hot in the reverberatory, and the zinc in part volatilizes; then the doors are opened and the remainder of the zinc is oxidized, and with some lead oxide is skimmed off. This is repeated until the zinc is entirely removed.

When refined in a kettle, steam is forced into the molten charge; the zinc and a little lead oxidize and form a scum, which is skimmed off.

The desilverized and refined lead is run into iron molds on wheels, and when cooled is ready for the market. The amount of marketable lead obtained is about 80 per cent of the impure lead. By using the Howard "stirrer," "skimmer" and "press" for the gold and silver crusts, 85 per cent has been obtained and 70 per cent of the zinc recovered.

An older process for desilverizing lead is the Paterson Process. It is found that when molten lead is cooled slowly, crystals of lead form which contain less silver and other impurities than the remaining molten mass. By repeated crystallization the silver is concentrated in a portion of the lead, and the remainder is almost free from silver. The silver-bearing portion, which must be cupelled, is about 30 per cent of the whole against 5 per cent in the Park's Process. The Paterson Process is not used in the United States.

The working up and recovery of all the by-products formed in the smelting of lead is a very important and very complex part of the process.

PROPERTIES OF LEAD.

Lead is the softest and heaviest common metal. It is very malleable and ductile, but has little tenacity. Lead is insoluble in sulphuric acid of moderate strength and is not much affected by cold hydrochloric acid. It is used in chemical works in the manufacture of sulphuric acid and for other purposes. Ordinary water has little effect on lead. Pipes used for conveying water are soon covered with a thin layer of carbonate and sulphate of lead, which is insoluble and prevents further action.

Water from swamps, etc., however, dissolves small amounts of lead, which makes its use dangerous for domestic purposes. Water from new pipes or pipes which are not kept constantly full should not be used for household purposes, because of danger from poisoning.

Lead is not affected by dry air, but is slowly corroded in moist air.

TIN.

This metal was known to the ancients, and very successfully used by them for hardening copper. The most important ore is tin-stone, $Sn\ O_2$, and the principal mines are in Cornwall, England, and Banca in the East Indies.

The smelting is conducted in a reverberatory furnace. The concentrated ore, mixed with finely divided anthracite coal and with a little lime is heated on the bed of the furnace. The tin is produced and runs into the depressed center of the furnace, from which it is tapped and cast into pigs. This impure tin is refined by liquating and poling.

PROPERTIES AND USES.

Tin is white in color with a slightly yellowish shade. It has a peculiar odor, and when bent it gives out a crackling sound known as the "tin cry." It has little tenacity, considerable ductility, and is very malleable. It can be worked at about the boiling point of water, but becomes very brittle at 400° F. It can be rolled into very thin sheets; tinfoil being sometimes only one-thousandth of an inch thick. On account of its ductility it is readily made into tubes, wire, etc.

The bulk of this metal is used for tin plate. Thin sheets of mild steel are carefully cleaned and annealed and then dipped in a bath of molten tin covered with a layer of tallow. They are then passed through rolls to remove the superfluous tin, leaving a very thin coating of pure tin on both sides of each sheet. Tin plate finds numerous uses in the canning industries, for household utensils, etc.

Almost all of the remaining product is used for making alloys of tin, and only a comparatively small amount is used for pipes, sheets, etc., on account of the high price of this metal.

ZINC.

A large proportion of this metal is obtained from the ore called Zinc Blend, ZnS; the carbonate and silicate are also important ores, and considerable zinc is obtained from Franklinite.

In the metallurgy of zinc advantage is taken of the volatility of this metal. It can be distilled unchanged at 1040° F. The ore is roasted to oxide of zinc, ground and mixed with finely divided fuel and heated to a bright red in gas heated retorts. The carbon takes the oxygen from the zinc oxide, forming CO gas, and the zinc is set free and distills off. It is condensed in iron tubes which are kept at such a temperature that the zinc remains liquid and runs into a receiving vessel.

This zinc contains iron and other impurities, and is purified by redistillation. It comes on the market cast in slabs, and in this form is called "spelter."

PROPERTIES AND USES.

Zinc is a bluish white metal, brittle and crystalline. It is quite ductile at a temperature of 248° F., but is so brittle at 390° F. that it can be crushed to powder.

Zinc is readily dissolved by acids and alkalies, but is not affected by the weather. It is very largely used for galvanizing iron, which is done by dipping the carefully cleaned iron in a bath of molten zinc, using sal-ammoniac as a flux. Zinc protects the iron from oxidation, and is effective as long as any zinc remains on the iron, being the reverse of the action of tin plate which causes the iron to rust more quickly as soon as there is any flaw in the coating. Zinc is also used in making alloys and for batteries, sheets for roofing, etc.

ALUMINUM.

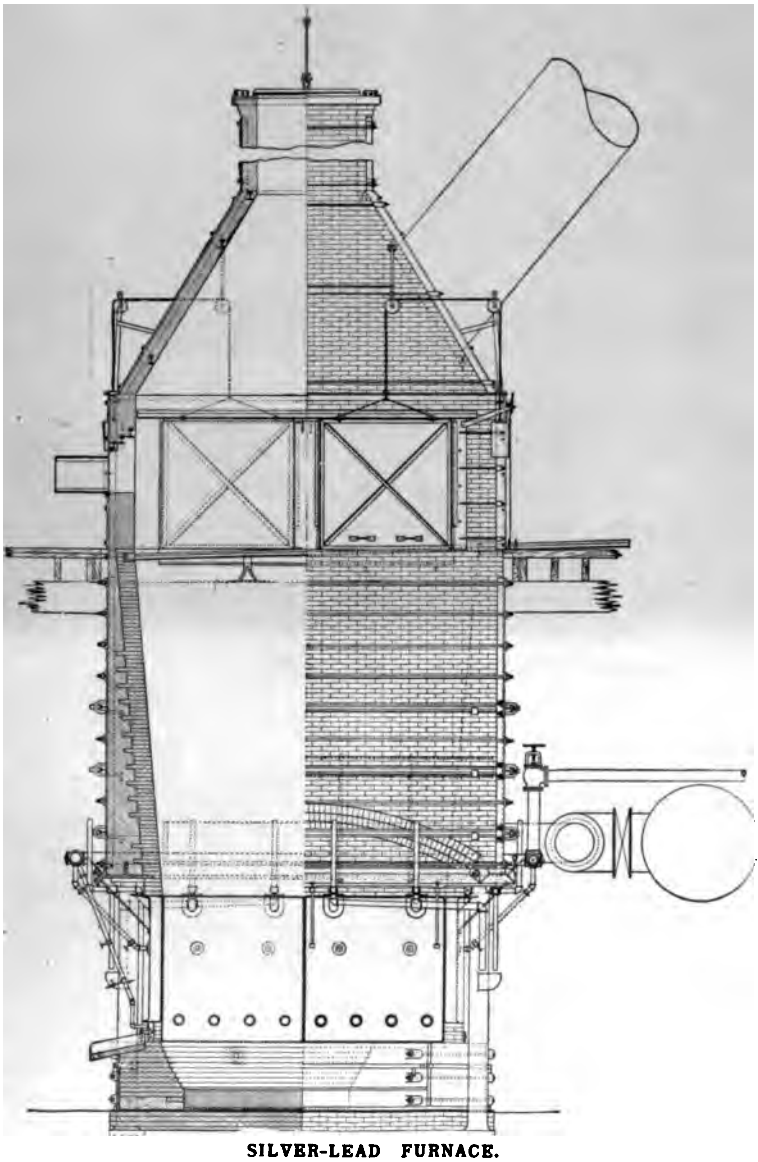
Aluminum has recently been transferred from a rare metal to one which, bulk for bulk is no more expensive than copper, by an electrolytic process invented by Hall. Beauxite, a hydrated oxide of aluminum is the important source of supply. Hall's process is conducted in a graphite lined vessel, and depends upon the property of cryolite — a double fluoride of sodium and aluminum, of dissolving fused oxide of aluminum. Cryolite melts at about 900° F. and then becomes a conductor of electricity. The bath is kept in a molten condition by a heavy current of electricity of low voltage. The oxide of alumina is sprinkled on the top of the bath and quickly dissolves, and is reduced by electrolysis to metallic aluminum which settles in the bottom of the crucible, from whence it is drawn from time to time.

If pure aluminum is desired the oxide of alumina used is obtained by a chemical process from beauxite.

PROPERTIES AND USES.

Aluminum is a grayish white metal, very malleable and ductile, and is a good conductor of both heat and electricity. It is acted on but feebly by sulphuric or nitric acid or by the organic acids. It is, however, dissolved by hydrochloric acid and the alkalies. Its most remarkable property is its extreme lightness, it being only about one-third as heavy as iron. It is fairly strong and imparts great tensile strength to its alloys. Good castings can be made from it, although the shrinkage on cooling is considerable. It can be worked cold, and is readily formed into sheets, wires, tubes, etc.

It is replacing copper to some extent as an electrical conductor, and is used for making a high class of kitchen utensils and a great variety of small ornamental articles. One objection to its use for some purposes is that it can be soldered only with difficulty.



SILVER-LEAD FURNACE.

Allis-Chalmers Co.

TABLE OF METALS.

NAME.	Specific Gravity.	Melting Point. Fahrenheit.	Electrical Conductivity. Silver = 100.	Heat Conductivity. Silver = 100.	Tensile Strength. lbs. per sq. in.	Weight per cu. in. in lbs.	Weight per cu. ft. in lbs.	Approximate Price per pound in Pigs, Billets, etc., 1902.
Cast iron	7.0 to 7.7	2100°	12.0	11.4	13,000 to 30,000	.260	445	¾¢
Wro't Iron	7.4 to 7.8	3000°	16.0	11.9	40,000 to 60,000	.278	485	1¾¢
Steel 0.1% C.	7.6 to 7.8	2500°	12.0	11.6	50,000 to 65,000	.283	490	1½¢
" 0.2% "					60,000 to 80,000			
" 0.4% "					70,000 to 100,000			
" 0.6% "					90,000 to 120,000			
Copper	8.8 to 8.9	1930°	99.9	73.6	25,000 to 50,000	.320	555	14¢
Lead	11.2 to 11.4	620°	8.3	8.5	1,600 to 2,400	.410	709	4½¢
Tin	6.9 to 7.3	446°	15.0	14.5	3,000 to 5,000	.263	455	25¢
Zinc	6.8 to 7.2	774°	29.0	19.0	5,000 to 20,000	.258	446	4¾¢
Aluminum	2.56	1100°	63.0	38.0	12,000 to 23,000	.093	160	30¢
Bronze	8.7	1550°	6.5		29,000 to 60,000	.313	541	20¢
Brass	8.4		22.0	23.6	30,000 to 40,000	.300	519	13¢

ALLOYS.

Mixed metals give us alloys, many of which possess useful and valuable qualities not found in the pure metals. The ancients were skilled in making bronze and brass, and many of their products cannot be surpassed at the present day.

In general the alloys of copper with tin are known as bronze, and with zinc as brass, but zinc is frequently added to bronze to cheapen it or change the color, and tin is often added to brass to harden it, so that the line between them cannot be sharply drawn.

There are countless combinations of metals, but only a few are of general importance. The table given includes most of these with their approximate composition, although each foundry has its own special mixtures. In making alloys, the most infusible metal is melted first, and the others are dropped into the crucible in small lumps, the most volatile being added last. A layer of charcoal is frequently thrown on the surface of the metal to prevent oxidation. In many alloys the metals begin to separate on standing, in which case it is necessary to mix well and pour at as a low temperature as possible, so that the casting will solidify quickly. This is helped by casting in iron moulds. Some metals can not be alloyed in all proportions; thus copper will take up only a small proportion of lead.

To produce finest quality alloys only pure metals can be used, as small amounts of impurities have a very decided effect, just as in the case of iron and copper. The method of making is also important in determining the quality of an alloy. In general alloys which are to be worked into sheets, tubes and wires must be more pure than those required for castings. A small proportion of lead is said to help the rolling qualities of brass, and a very small percentage of phosphorus in bronze makes it more fluid and free from blow holes. The alloys of metals with mercury are called amalgams. One method of extracting metallic gold from its ores is amalgamation, and the effect of amalgamating the zinc in batteries is well known. Formerly alloys were thought to be chemical combinations of metals, but now it is generally considered that they are simply mixtures of metals, sometimes being solidified solutions in each other.

TABLE OF ALLOYS.

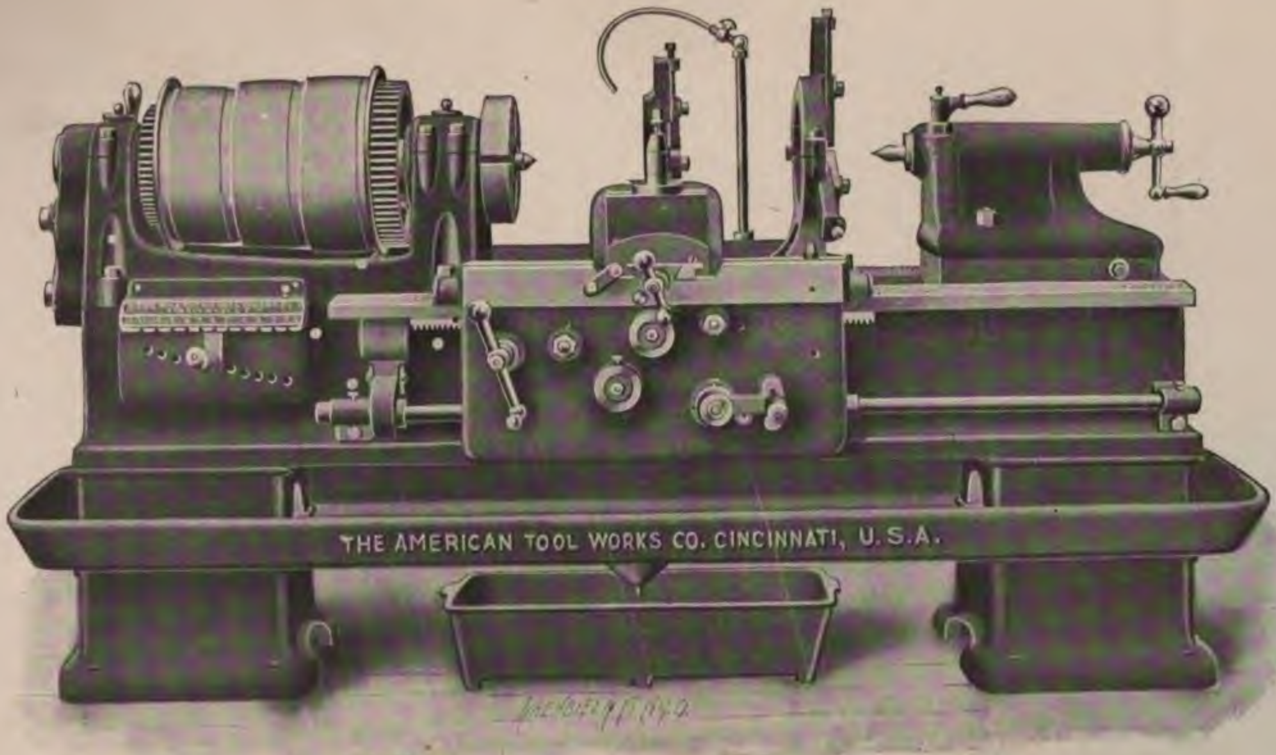
Approximate Percentage Composition by Weight.

Name.	Copper.	Tin.	Zinc.	Lead	Other Metals.	**Uses and Remarks.**
Gun metal	91	9				Ordnance, bearings, castings
Bell metal	75	25				Bells, gongs; rather brittle
Bronze coin	95	4	1			Coins, medals
Phosphor bronze	92½	7			½ Phosphorus	Strong castings, heavy bearings
Manganese bronze	89	10			1 Manganese	Propeller blades, pumps. It is non-corrosive and very strong
Aluminum bronze	90				10 Aluminum	Very high tensile strength
Valve metal (best)	88	12	2			Sometimes called "composition"
Valve metal	83	2	15			Cheaper valves, cocks, etc.
Bearing metal	77	8		15	Trace of Phosphorus	Heavy bearings, used on railroads
Brass (common)	66⅔		33⅓			Sheets, wire, tubes, pipe fittings
Muntz metal	60		40			Bolts, nuts; malleable at red heat
Delta metal	56		42		2 Iron	Strong sheets, etc: "Tobin bronze" is a delta metal with a little tin and lead added.
Brazing metal (soft)	50	12½	37½			Low melting point
Brazing metal (medium)	50		50			For copper work
Brazing metal (hard)	75		25			Strongest
German silver	60		20		20 Nickel	Ornaments, resistance wire; composition variable
Fusible plug		10		86	4 Bismuth	For steam boilers
Common solder		50		50		
Fine solder		66⅔		33⅓		
Babbitt's metal	3	89			8 Antimony	The original Babbitt; for bearings
Babbitt's metal				80	20 Antimony	Commonly called Babbitt; used for repair work on bearings
Pewter		80		18	2 Antimony	Plates, mugs, etc.; composition variable
Britannia metal		90			10 Antimony	Table wear, ornaments; composition variable
Type metal				80	20 Antimony	Type and lithograph
Regulus metal				88	12 Antimony	Acid cocks, valves, etc. Sometimes called white metal.

THE ECONOMY OF HIGH-SPEED STEEL.

In the finishing process in the machine shop, there has been a wonderful development, during the past few years, in the rapidity with which metal can be removed, as well as in the character of the surfaces obtained. For many years, tools made from cast steel, crucible steel, or tool steel (all these names referring to steel of practically 1 per cent carbon), were the only tools that could be employed in the machine shop for the removal of metal. The good old tempered steel tool did its work well, and, in spite of the development of other steels, it has not by any means been entirely superseded. One of the great advantages of the old carbon tool steel is that its manufacture and use have covered so long a period of time that the quality of the steel in the bar, and the results obtained by the shop smiths, have become very uniform.

Tungsten Steel. The first indication of improvement on carbon tool steel, in the line of ability to "stand punishment", was the introduction of the so-called "Mushet" steel, some fifteen or twenty years ago. This was a steel containing, in addition to the elements usually found in tool steel, a certain percentage of tungsten. The name "Mushet" was applied to the steel on account of the fact that R. Mushet of Sheffield, England, was the most prominent manufacturer of this grade. Tungsten steel has several peculiarities that distinguish it from carbon steel. It is an extremely hard steel, and cannot be easily forged. It has the peculiar property of being always hard; that is, when heated and forged, it resumes its hard condition after slow cooling. Dipping it when at a red heat, in water, will almost invariably cause the steel to fly in pieces. On the grinding wheel, tungsten steel shows a dull red spark entirely different from the spark given off by carbon tool steel. Owing to its permanently hard condition, forging and grinding were the only processes by which tools could be shaped, and consequently this steel was used for lathe and planer tools almost exclusively. During recent years, methods have been found for annealing tungsten steel to a limited degree, so that its use is no longer limited by its hard and brittle nature. Another point of difference that calls for consideration is that of price.


THE AMERICAN TOOL WORKS CO. CINCINNATI, U.S.A.

AMERICAN HIGH-SPEED MANUFACTURING LATHE.

The best carbon tool steel costs about fifteen cents per pound, while the tungsten steels are worth about forty-five cents.

The results obtained by the use of tungsten steel were of great importance. The steel would stand a very much higher temperature than carbon steel before losing its edge. Therefore—for "roughing" cuts, especially—it was found that considerable time could be saved by cutting at a higher rate of speed. It was discovered, however, that the tungsten steel would not maintain a clean, sharp-cutting edge suitable for light finishing cuts, so well as would the carbon steel. Therefore the use of tungsten steel was limited almost entirely to the roughing cuts.

Heat Treatment for Tool Steels. Several years ago a process of heat treatment for tool steels—called the "Taylor-White" process—was responsible for another step forward in the rapidity of shop operations. While this process was more particularly adapted to a certain brand of self-hardening steel, it was claimed that its use would improve the heat-resisting quality of any good brand of tool steel. It would be well to note at this point that the whole matter of increased speed of cut seems to hinge on the temperature at which the tool will lose its edge. Owing to the fact that the Taylor-White process was not generally understood, its use did not become very extended, but it paved the way for the introduction of the modern high-speed steels, which depend for their successful operation on a heat treatment somewhat similar to that employed in the Taylor-White process. There have sprung up a multitude of brands of high-speed steels, which are designated by various names, such as "air-hardening", "self-hardening", "high-speed", etc. The chemical composition of these steels is generally not made public, and there has been a great deal of mystery attached both to the material itself and to its method of treatment. This has prevented a more rapid introduction.

High-speed steel can be annealed, and cutting tools of all kinds can be made from it. In this it differs from the tungsten steel. It is also higher than the latter in price, costing about seventy-five cents per pound. To speak of the economy of high-speed steel at such a price implies, of course, that the results must fully warrant the outlay. It is believed that the judicious use of high-speed steel is in reality economical. By judicious use is meant use where the results are clearly superior to those obtained by the employment of the cheaper and slower working steels.

On account of the high price of these improved grades, it has been found economical to use the steel in small sections which can be carried in a case-hardened mild-steel holder. Typical examples are shown in the accompanying illustrations. While these holders are very handy, and certainly save large amounts of costly steel, still they cannot be made as rigid as a solid forged tool; and, for the very heaviest work, a tool forged from the solid is still preferred. High-speed steel, however, is very brittle, and, if forged solid, should be carried out to the cutting edge in as large a section as possibie. If used in a holder, it must be supported very nearly out to the cutting edge.

OFFSET TOOL HOLDER (LEFT HAND).

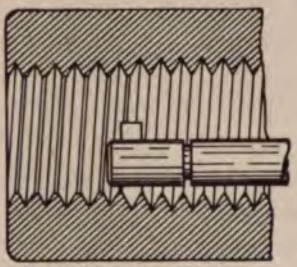
Holders for this costly steel usually provide means of clamping by a set screw. Some method of doing away with the vibration inseparable from a screw is desired; and it has been suggested and proven to be good practice to solder or braze small pieces of high-speed steel onto soft-steel shanks. This has in many cases proved very satisfactory.

The Test of Results. There have been so many extravagant claims made in regard to results alleged to be accomplished by the use of high-speed steel, that many men have concluded that this steel could not possibly fulfill them. As a matter of fact, in many cases cited, it cannot. Actual results, however—sufficient to establish the economy of these steels—can be obtained in abundance, and a few general figures on relative speeds may prove of value. With ordinary carbon-steel tools, an average figure for the cutting speed would be about 20 feet per minute for mild steel, 30 feet per minute for wrought iron, and 40 feet per minute for cast iron. These figures, of course, are merely approximate, but they fairly represent

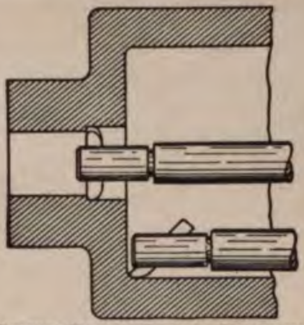
OFFSET TOOL HOLDER (RIGHT HAND).

average practice. By the use of tungsten steel, the speed for roughing cuts was increased about fifty per cent, while heavier cuts, also, could at the same time be taken. The later high-speed steels, however, show great improvement over these figures, the speed for roughing cuts being increased to about 50 feet a minute for mild steel and wrought iron, and 75 to 80 feet per minute for cast iron. Finishing cuts, especially for mild steel, can be taken at rates which appear to be little short of marvellous, a speed of from 150 feet to 200 feet per minute being not uncommon in the finishing of mild steel.

One of the peculiar things connected with the development of high-speed steel, has been the simultaneous development of grinding. The process of grinding has no place in this article, but it may be noted that the high-speed steels are being extensively used for roughing cuts, while the finish is obtained by grinding. As an instance of work of this character might be cited the turning of cast iron at a cutting speed of 75 feet per minute—depth of cut $\frac{1}{8}$ inch, with a feed of $\frac{1}{4}$ inch per revolution, leaving $\frac{1}{32}$ inch over the correct size at the bottom of the groove. The finish obtained by grinding is superior to, and more rapid than, that secured by fine turning, filing, and polishing.



TOOL CUTTING A THREAD.



DOUBLE-ENDED CUTTER ROUGHING OUT CORED HOLE. ALSO ANGLE CUTTER BORING AND FACING END.

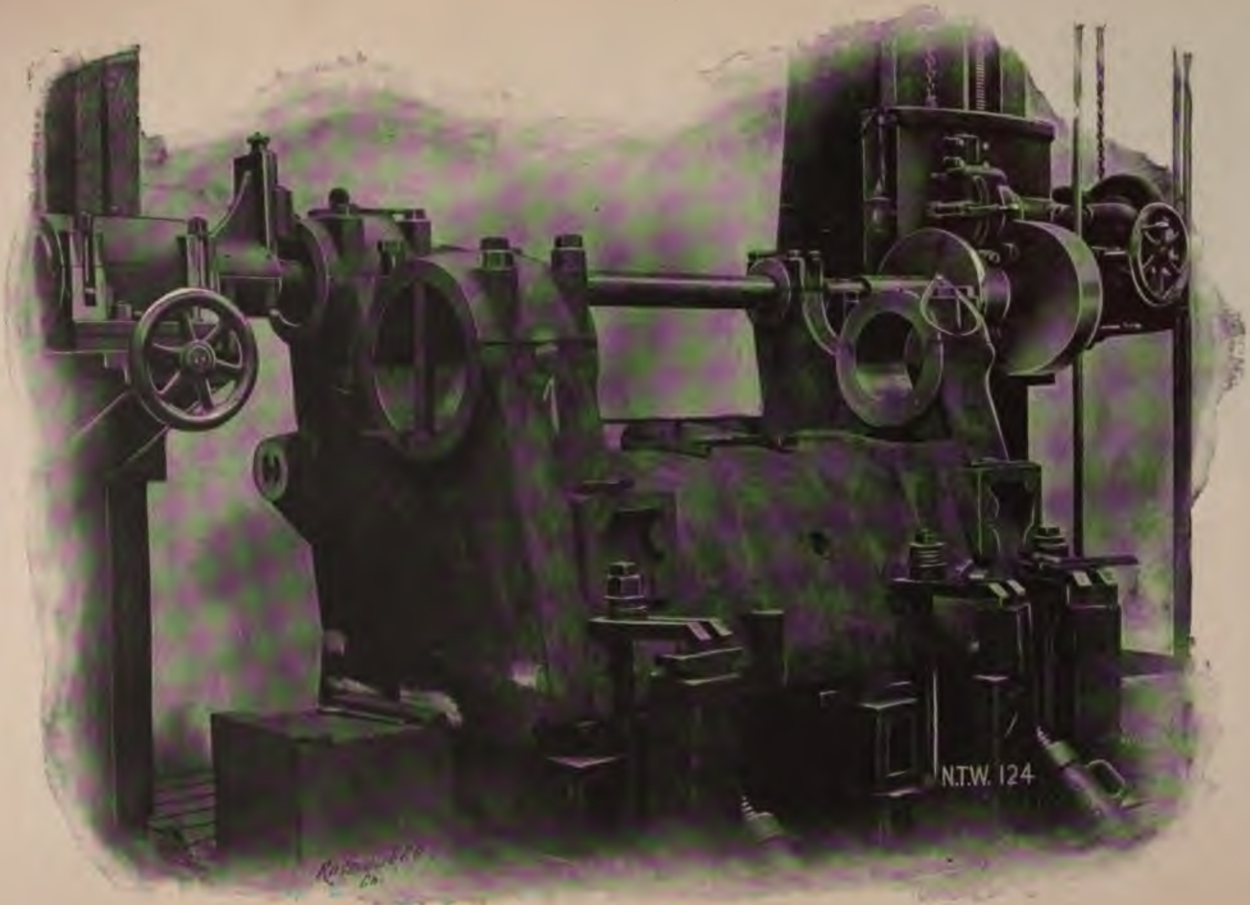
People have become discouraged—in some instances, possibly, disgusted—with high-speed steel, on account of the oft-prevailing tendency of human nature to wish to get something for nothing. There are many brands of this steel, and the methods of working, especially as far as the heat treatment is concerned, are as numerous as the steels themselves. Nearly all steel salesmen, even if they do not insist on leaving a sample of their steel, are perfectly willing to do so; and the result is the tool room soon acquires a collection from which the identifying marks are almost sure to be lost, whereupon there is trouble for the tool dresser and the machinist. It is not intended by this to advise the exclusion of new materials and processes, but more particularly to recommend keeping the experimental and the commercial ends of one's business separate and distinct from each other. It is well to try thoroughly all brands of steel offered; but it is not wise to have more than one brand for shop use.

The steel salesman, also, in numerous instances, is inclined to make claims for his particular brand, which claims, in many cases, cannot be substantiated. This does not imply that the results will not show a distinct advantage over the old carbon steels. The purchaser should not expect to obtain results fully equal to those claimed by the agent, the claims of the salesman being generally based on short laboratory tests, and sometimes, it is to be feared, colored to suit the prospective purchaser. If a substantial saving in time can be made, there is economy in the use of high-speed steel, and the fact that still better results than this are claimed, does not prove that its use is not economical.

There is an economy in the use of this steel, which, while it may be attributed to the material, is in a sense not directly concerned with its use. It is a well-known fact that so simple a matter as speeding up the shafting has a tendency to quicken the life of the whole shop. This is true not only as regards the actual output of the machines; but it also actually quickens the physical movements and mental grasp of the workmen themselves.

In a recent address before an engineering society, a speaker used this expression, "High-speed steel is developing high-speed machinists." This remark is strictly true; and, although the introduction of this steel will be opposed by the slothful workman, its influence upon the great majority of men will be distinctly beneficial.

To sum up in a word, the economy of high-speed steel may be said to comprise saving of time in the machine operation; better mechanical results, especially if we include the simultaneous development of grinding; and finally—perhaps the most important of all—the quickening, physically and mentally, of the workman.



BORING AND FACING HEADSTOCK OF LATHE.

Niles-Bement-Pond Co.

MACHINE SHOP WORK.

PART I.

MACHINE shop work is usually understood to include all cold metal work in which a portion of the metal is removed to make the piece of the required shape and size either by power-driven or hand tools. However, there are some branches of cold metal work, such as sheet-iron work and coppersmithing, that are not included in machine shop work.

HAND-OPERATED TOOLS.

As the hand-operated tools are much simpler, and as the operations performed with them are in every case more typical, their description and use should precede that of power-driven tools. It should be clearly understood, however, that machine shop practice involves the use of both classes at the same time. Even hand tools are not used in the same order on different classes of work; it is, therefore, impossible to describe them in the order of use. Simplicity of construction and operation will be the guide for treatment in the following pages.

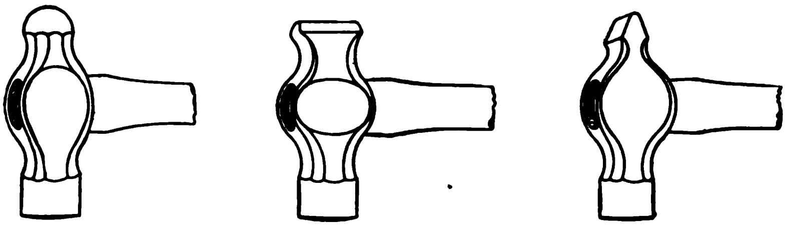


Fig. 1.

The machinist uses **hammers** of three shapes: ball pene, cross pene, and straight pene. See Fig. 1. The first named, the ball pene, is the most common; it varies in weight from four ounces to three pounds. The cross and straight pene hammers vary from four ounces to two pounds and are used principally in riveting. All hammers are made from a good grade of cast steel, hardened, and drawn to a blue color at the eye and a dark straw on the face and pene. The eye is elliptical in shape, and the handle is fastened by driving wedges, either wood or iron, into the end of the handle, thus spreading it to fill the eye. The handle is of hard wood, preferably hickory, and of a length suited to the weight of the hammerhead. When the handle is properly inserted, the axis of the head stands at right angles to the axis of the handle.

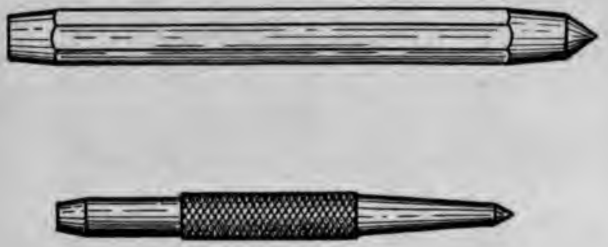


Fig. 2.

Soft hammers are used for striking heavy blows where the steel hammer would bruise the metal or mar the surface. They are made of rawhide, copper, or Babbitt metal, and vary in weight from six ounces to six pounds. They are subject to rapid wear, but are indispensable in setting up and taking down machinery. Those of metal are so constructed that the soft metal can be recast in the handle.

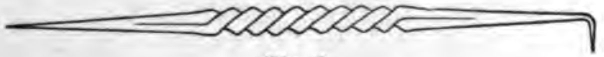


Fig. 3.

The *prick punch*, Fig. 2, is made of cast steel with a hardened conical point of about 60 degrees. It is about 3½ inches long and ¼ inch in diameter. It is used for making very small holes at intervals of about ½ inch on a line.

The **center punch**, also shown in Fig. 2, is made of the same general appearance as the prick punch, but is about 5 inches long, ½ inch in diameter, and has a point of about 90 degrees. The principal use is to make center holes marking the centers on the ends of pieces to be turned.

Both prick punches and center punches are usually made of hexagonal steel; but if round stock is used, the grip should be fluted or knurled to prevent slipping in the fingers.

The **scriber** or **scratch awl**, Fig. 3, is made in many forms, but consists essentially of a cast-steel rod about 8 inches long and $\frac{3}{16}$ inch in diameter, with a long, slender, hardened point at each end; frequently one point is bent at right angles to the shank. As the name indicates, this tool is used for marking lines on the surface of metal.

The **surface gauge** is used in laying out work for the bench, lathe, or planer. The ordinary form consists of a heavy base, an upright, and a scriber or scratch awl; the upright being firmly fastened to the base. In the universal gauge, the upright is pivoted at the base so that it may be used at any angle. In some forms the base is grooved in order that the gauge may be used on cylindrical work as well as on flat surfaces. See Fig. 4.

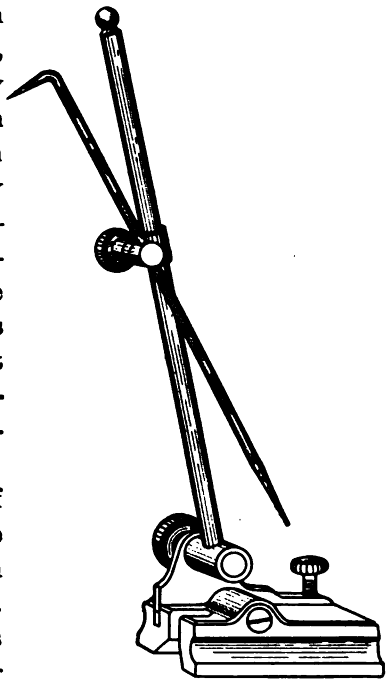


Fig. 4.

To use the gauge, the part of the work to be laid out must be prepared so that lines drawn on the surface will show distinctly. A rough or unfinished surface is covered with chalk, a finished or bright surface should be copper-plated by applying a thin coating of copper sulphate solution with a brush or a piece of waste. The work and gauge are then placed on a true surface and the scriber adjusted to the desired height. The line is drawn by moving the surface gauge along on the true surface, keeping the point in contact with the work. After scribing the lines, it is well to place light prick punch marks at frequent intervals along the lines, so that the position may be found if the chalk or copper sulphate becomes effaced.

The **straight edge** consists, in its simplest form, of a thin flat piece of steel, generally unhardened, with accurately finished straight edges. The very small sizes used in fine work are sometimes made with a hardened knife edge. A non-conducting handle is sometimes used with the small sizes to prevent distortion from the unequal heating due to handling. The short lengths used for ordinary shop purposes have one edge beveled, and are thick enough to avoid bending. See Fig. 5. The larger sizes, from three to ten feet or more in length, are usually made of cast iron with one finished edge. The metal is so distributed as to combine lightness with great rigidity, the tendency of the ends to drop being resisted by the truss-like form of the casting shown in Fig. 6. The flat form is used, in connection with the scriber, to draw accurate straight lines on plane surfaces. All styles are used to test the truth of plane sufaces by placing the straight edge on the surface to be tested in not less than the six positions shown in Fig. 7.

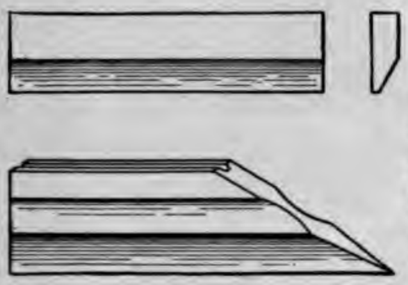


Fig. 5.

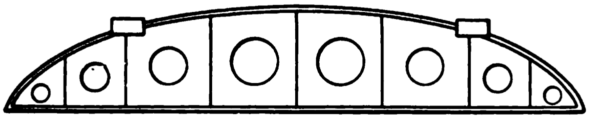


Fig. 6.

For drawing lines and laying off distances on curved surfaces, such as shafts, a combination of two straight edges, or a straight edge and a rule, is used. This is often called a *key seat rule* because its chief use is laying out keys on shafts. However, many machinists call it a "box-rule." It is usually made in one piece, although some manufacturers provide clamps by which the two separate pieces are held at right angles to one another. A more simple combination is shown in Fig. 8, the second scale being represented by two special clamps.

The simplest form of square, called the *flat square* (Fig. 9), is a combination of two straight edges at right angles. This is a useful form where the square is laid on the work. One blade is usually graduated on the inner edge, and the other on the outer edge. The flat square is not hardened.

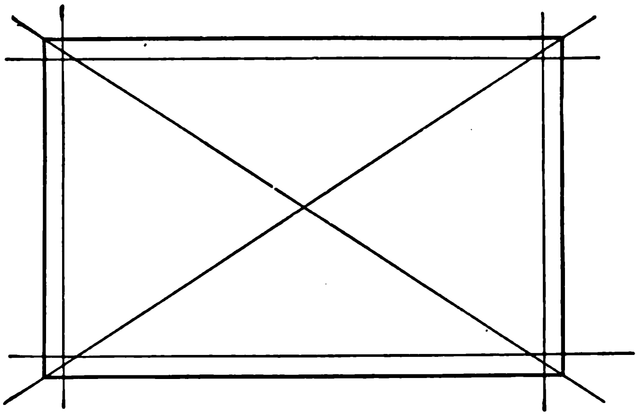


Fig. 7.

The **try square**, shown in Fig. 10, consists of a beam and a blade at right angles. The beam is much thicker than the blade and somewhat shorter. Try squares are made both unhardened and hardened. The unhardened form has graduations on one edge, and is called the graduated try square. The hardened type always has a hardened blade, sometimes a hardened beam as well, and is not graduated.

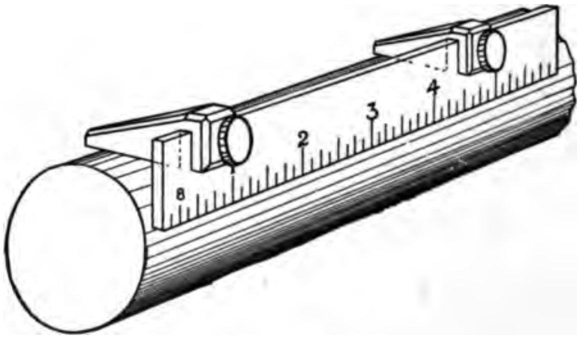


Fig. 8.

The try square is used as a guide to draw lines at right angles to each other and to given surfaces; to erect and test perpendiculars to plane surfaces; to test the truth of a given surface at right angles to another surface; in short, it is used wherever an accurate measurement of 90° is required. When used for testing the relation of two surfaces, the beam is pressed closely against the correct surface, and the blade brought carefully down to the surface under consideration. This does not prove more than that a line at the particular point tested is or is not at right angles to the true surface. By using the blade as a straight edge parallel to the true surface, errors in that direction may be corrected and the surface be made plane.

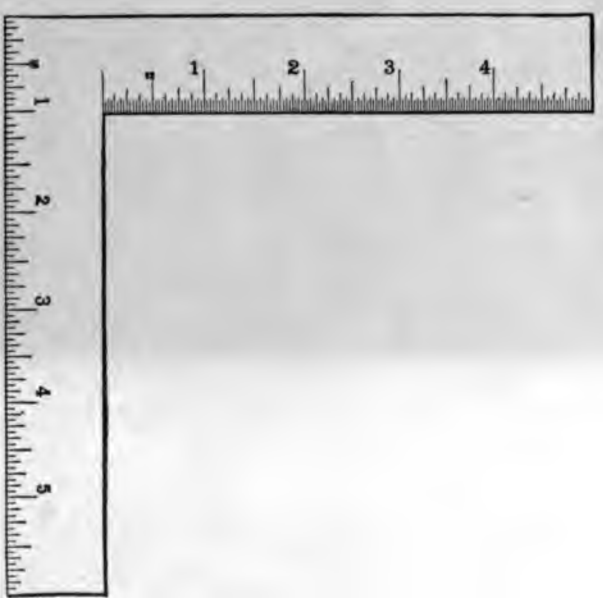


Fig. 9.

In many cases it is necessary to test the relation of lines and surfaces which are not at right angles to each other. For this purpose a **bevel** is used in which what corresponds to the blade of the square is made adjustable. Its construction is seen in Fig. 11, and its use is similar to that of the square.

The bevel can be adjusted only by direct application to lines or surfaces having the proper angular relation. It often happens that such adjustment is not feasible, and therefore a registering device, in the form of a graduated arc, is applied to the bevel, making what is known as a **protractor,** shown in Fig. 13. This tool can be used to find the angular relation in degrees or to produce that relation by setting to the proper point on the graduated arc.

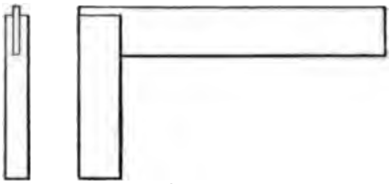


Fig. 10.

As the center of a circle is found at the intersection of any two diameters, an instrument for readily finding that point is a great convenience. In Fig. 12 is shown a combination of straight edge and square called a **center square,** which accomplishes this result. As one edge of the rule bisects the angle of the square, it is evident that a line drawn by that edge passes through the center of any circular piece to which the square is applied. Centering the ends of round bars or circular work of any kind is the principal use of this tool.

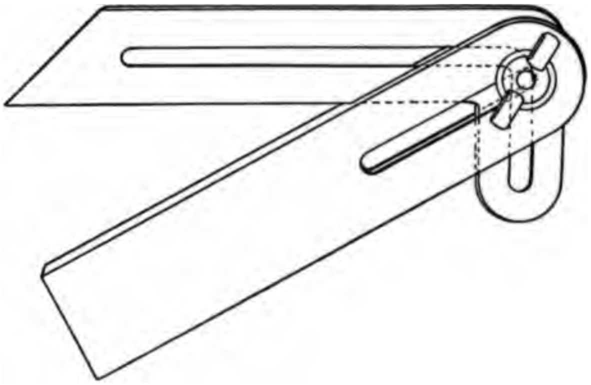


Fig. 11.

The center square, bevel, and protractor are furnished in a combination set as shown in Fig. 14. The ability to change the length of the blade is one of the great benefits of this construction.

MEASURING TOOLS

The testing tools thus far described are used for comparing the angular relation of lines and surfaces, and may be called tools for angular measurement. We now turn to the consideration of instruments for measuring distances and sizes, or tools for linear measurement.

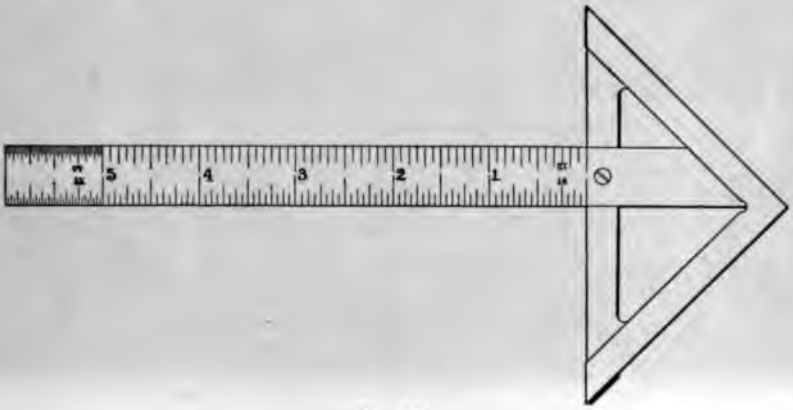


Fig. 12.

The most common tool for *linear measurements*, and one which hardly requires description, is the so called carpenter's or two-foot rule. This is very convenient for the machinist in making measurements which are not required to be very accurate. For

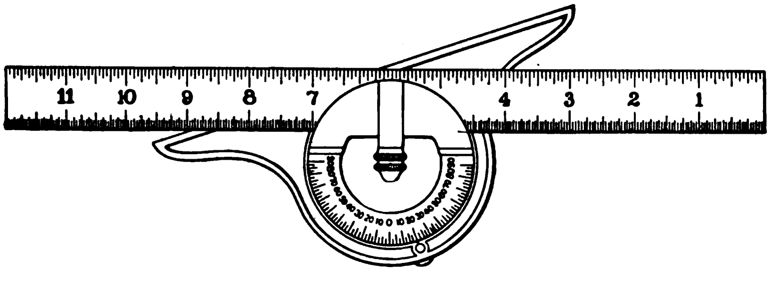


Fig. 13.

work of greater refinement, the **standard steel scale** (Fig. 15) is used. This is in reality a divided or graduated straight edge and, as such, forms a part of several tools already described. The most common form of steel scale is flat, varying from one to forty-eight inches in length, and carefully hardened and ground. The graduations in the better class of scales are cut with a dividing engine, although the lines may be etched on the surface with a fair degree of accuracy. A thin and somewhat narrower form, called a flexible scale, is made in sizes from four to thirty-six inches. What are known as narrow scales are obtainable from four to thirty-six inches, and are of great convenience in certain cases. Besides these shapes, square scales are made in sizes from three to six inches in length, and the triangular form varies in length from three to twelve inches. Steel scales with the English system of graduation can be obtained with the inches divided in eighths, sixteenths, thirty-seconds, sixty-fourths; twelfths,

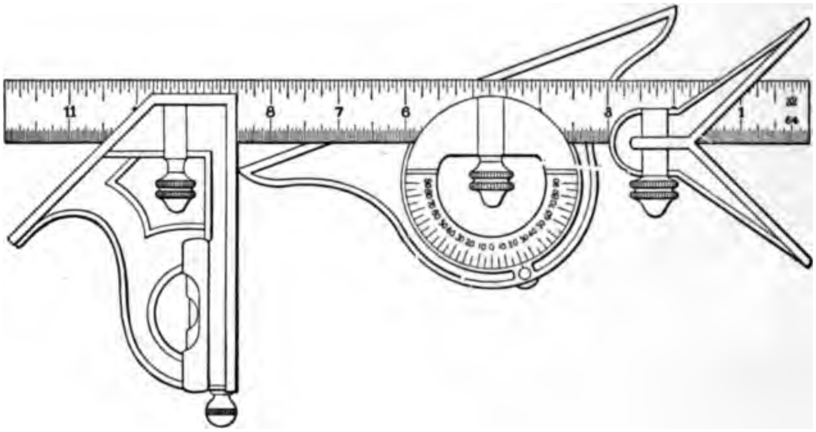


Fig. 14.

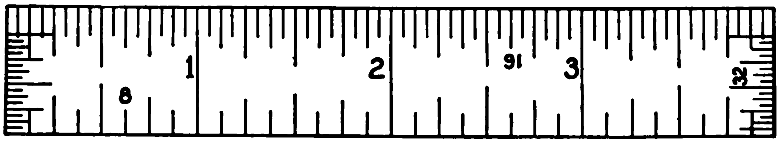


Fig. 15.

twenty-fourths; tenths, twentieths, fiftieths, and hundredths. Special scales are made with graduations especially adapted to such uses as gear blank sizing, etc.

The ends of flat rules are sometimes graduated, making what might be called a very short rule with a handle. Flat rules are sometimes graduated with Metric divisions as fine as one millimeter, and from five centimeters to one meter in length.

For transferring and comparing distances, **dividers** are commonly used. They are classified according to the style of joint and the length of the leg. The most simple joint is the friction, and like all frictional devices, is hard to set accurately. Lock-joint dividers can be moved freely to approximately the right position, the joint locked, and the adjusting screw used for the final setting.

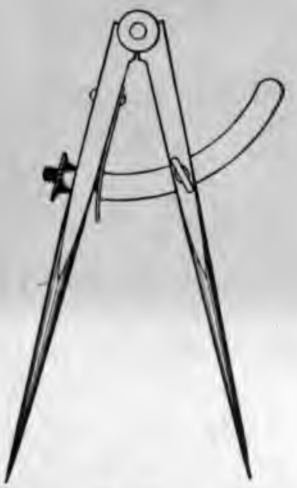


Fig. 16.

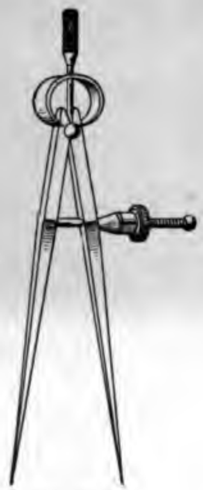
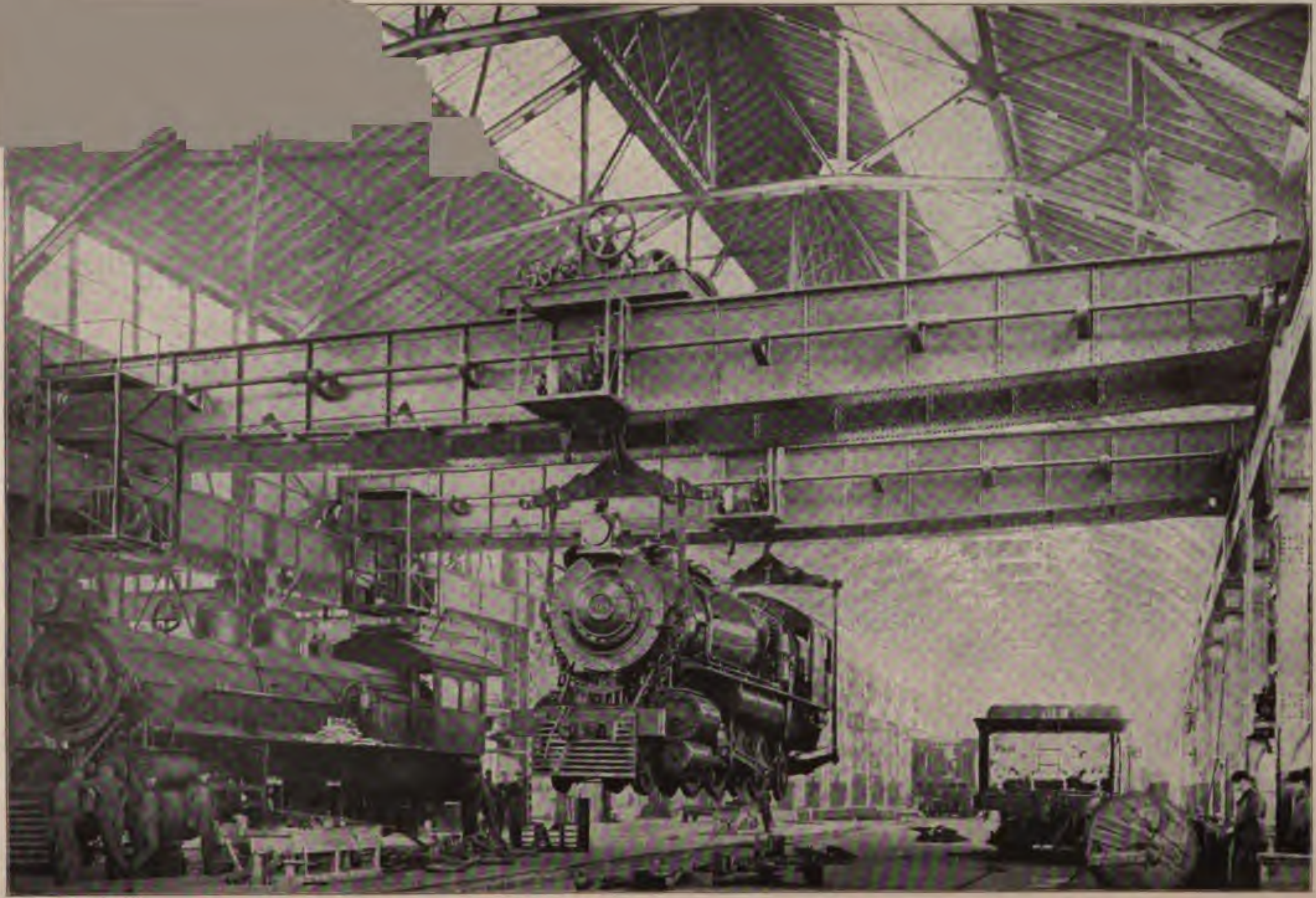


Fig. 17.

Wing dividers, Fig. 16, are of about the same construction as the lock joint, except that the fastening is made on the wing instead of at the pivot. The best of all forms has a spring adjustment as shown in Fig. 17. In this type, a spring tends to open the dividers, and the legs are closed against the spring by a nut working on a screw which is fastened to one leg and passes



TWO FOUR-MOTOR ELECTRIC TRAVELERS. Capacity 60 Tons.

freely through the other. The length of dividers varies from two and one-half to ten inches. The distance to which dividers can be opened is generally about equal to the length of the leg. For distances above ten inches, *trammel points*, diagram, Fig. 18, are convenient. They consist of hardened steel points attached to metal sockets, and can be used on rods of any length. One point may have a spring adjustment, and in that case can be set in the same manner as a pair of wing dividers.

Next in importance to the dividers as an adjustable distance gauge, are the **calipers.** Instead of having straight legs with sharp points, caliper legs are bent and have blunt points. As distances are to be measured both outside and inside of solid bodies, we have outside and inside calipers. The legs of outside calipers have a large curvature so that the calipers may be passed over cylinders of their greatest capacity.

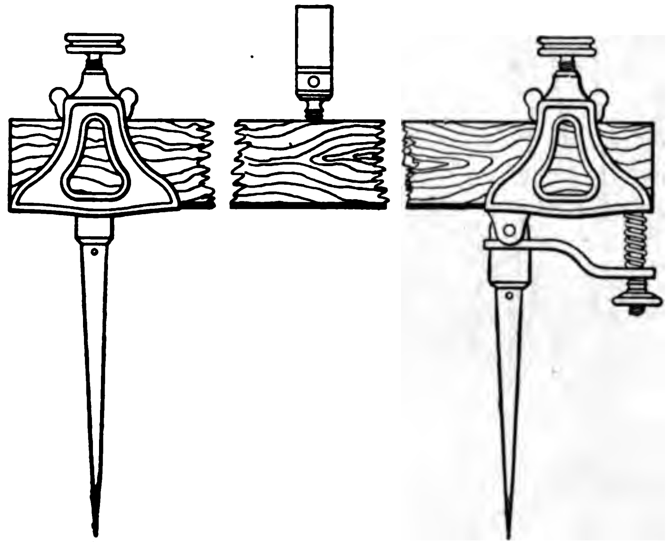


Fig. 18.

Inside calipers, Fig. 20, are more like dividers in general appearance, the ends being bent outward slightly and the points rounded. The same styles of joints used in dividers are used in calipers, and the size of calipers is also designated by the distance from the joint to the end of the leg. Spring calipers are made in sizes from two and one-half to eight inches, while the other styles vary up to twenty-four inches.

As it is sometimes necessary to make measurements behind shoulders and in chambered cavities, where the ordinary calipers could not be removed after setting, it is necessary to have calipers so arranged that they may be set, changed to clear the obstruction, and then reset accurately in the first position. This is accomplished by **transfer calipers,** shown in Fig. 19, in which one leg is temporarily fastened to a stub or false leg. After setting, this leg may be moved away from the stub, the calipers withdrawn, and the leg again placed in contact with the stub; the points will then be found to occupy the same position as when first set. Small curved legs may be used in place of points or trammels in calipering large objects.

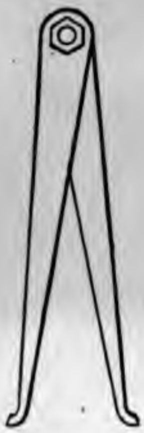


Fig. 20.

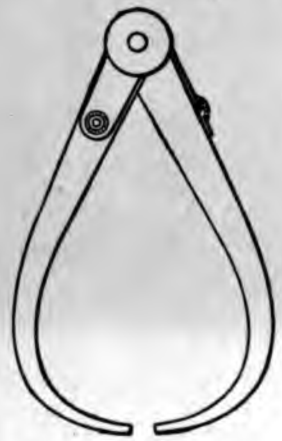


Fig. 19.

Both dividers and calipers are usually set by means of a scale. In setting dividers, place one point in a graduation of the scale, and move the other until it falls easily into another graduation which gives the required distance. Outside calipers are often set by placing one leg against the end of the scale and moving the other until it is opposite the middle of the graduation giving the required length. As the graduations are not mathematical lines, but have an appreciable width, this last precaution is one of great importance. Inside calipers are set by placing both the scale and caliper toe against a plane surface as shown in Fig. 21; the other toe is then set the same as the outside caliper.

Caliper legs are comparatively slender, are easily bent, and care must be taken in using them to see that the contact with the object being tested is very light. It is an easy matter to spring calipers of common sizes as much as one-sixteenth of an inch.

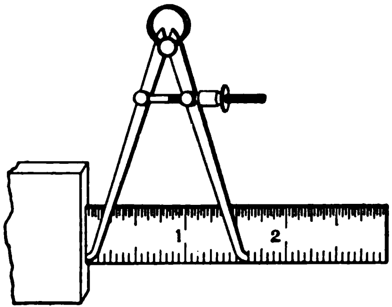


Fig. 21.

The **caliper square** is made by attaching a movable blade to the common square. In the ordinary forms it closely resembles a steel rule with two arms extending from it at right angles, one fixed near the end and the adjustable arm sliding along the scale with a clamping device for adjusting this movable arm. In order that the movable arm may be set accurately, caliper squares (Fig. 22), as at present constructed, have two clamps for the movable arm. The one carrying the thumb nut is to be first clamped in approximately the right position; the clamp on the movable arm being secured after the adjustment has been made by the nut. The sizes used vary from three inches up, and are limited only by the length of scales obtainable.

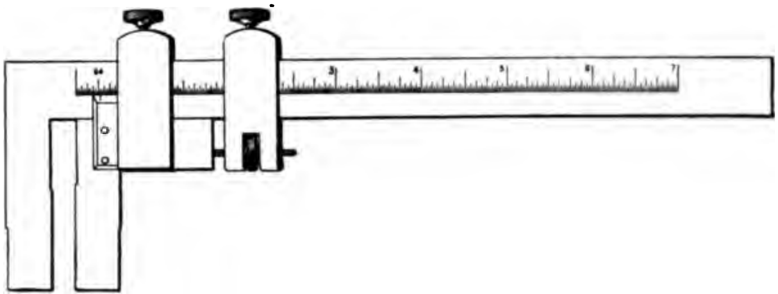


Fig. 22.

For measurements which are required to be more accurate than can be obtained by the preceding forms of calipering devices, the

micrometer caliper, Fig. 23, is used. The accuracy of its measurements is determined, not by direct setting to two lines, but by finely dividing the pitch of the measuring screw and furnishing means for reading these subdivisions. It is a registering as well as an indicating caliper, and thus serves the purpose of a common caliper in combination with a rule, but with a much greater degree of accuracy.

It consists, essentially, of a crescent-shaped frame carrying a hardened steel anvil B at one end and a nut of fine pitch at the other; the axis of the nut being at right angles to the face of the anvil. The outside of the nut, A, forms a projection beyond the crescent that is called the barrel. The measuring screw consists of a fine-pitched screw to fit the nut, combined with a measuring point C, having a face parallel with that of the anvil. Firmly attached to the outer end of this screw, is a thimble D, fitting closely over the barrel; the edge of this thimble is beveled so that graduations placed on the edge come very close to the barrel. A reference line is drawn on the barrel parallel to its axis and graduated to represent the pitch of the screw. The chamfered edge of the thimble is so divided that the movement of one division past the reference line on the barrel indicates a movement of the measuring point of one thousandth of an inch. For example: if the pitch of the measuring screw is one hundredth of an inch, there should be ten divisions on the

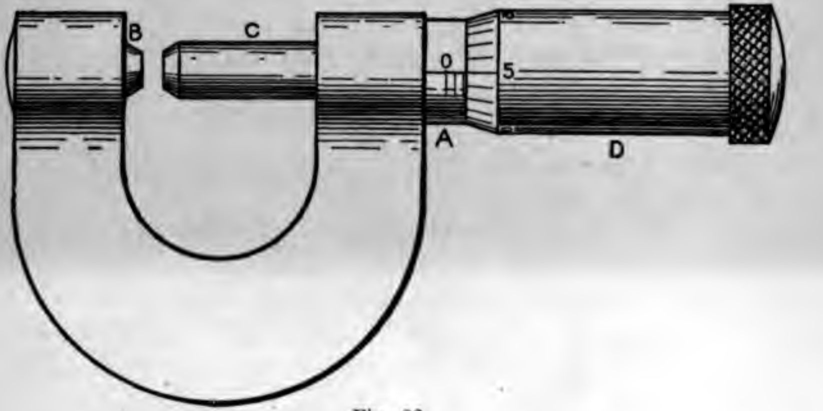


Fig. 23.

thimble; if one fiftieth of an inch, twenty divisions; if one fortieth of an inch, twenty-five divisions; if one twenty-fifth of an inch, forty divisions. Measuring screws having a pitch of one fortieth of an inch are commonly used, and every fourth division on the barrel lengthened and numbered to indicate tenths of an inch as shown in Fig. 25.

In using the micrometer caliper, it should not be set at the size required and pushed over the work, but should be screwed down until the measuring point C and anvil B are in contact with the work; the size may then be read from the relation of the thimble to the reference line on the barrel. The proper degree of pressure to be applied to the screw is acquired only after extended practice, and some manufacturers place a friction device on the thimble so that undue pressure cannot be exerted.

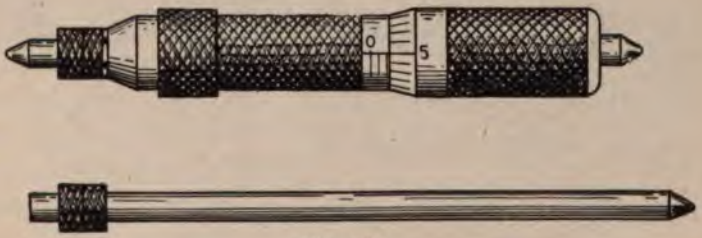


Fig. 24.

The micrometer caliper will not only indicate that the work is too large or too small, but will also show exactly the amount by which it differs from the desired measurement. This is a great improvement over the rigid form of calipers, and enables the workman to judge more accurately the progress of the work. This form of caliper is rapidly coming into favor in spite of its cost, and for this reason it has been described more at length than the common forms previously considered.

The range of motion of the measuring screw is usually limited to one inch. Various devices give the micrometer caliper a larger range of action. Micrometer calipers may now be purchased in combinations or sets giving a range from zero to twelve inches.

The application of the micrometer principle to inside measurements is not in general use, but is easy to arrange, and makes a very simple instrument, as shown in Fig. 24. It consists of an ordinary micrometer head, except that the outer end of the thimble carries a contact point, attached to a measuring rod which may be of any length. Two inches is about the shortest distance that can be measured with this device, but there is hardly any limit in length, as the rigidity of the rod is easily provided for. It is evident that such rigidity is harder to obtain in the curved shape necessary for outside measurement, and thus limits this form to about 12 inches, as above stated. The contact points in the outside type are parallel plane surfaces, and in the inside form are rounded points of small radius. Outside micrometers are provided with contact points of varying forms for measuring paper, threads, walls of tubes, etc. The shapes for these purposes will not be shown, but may easily be imagined.

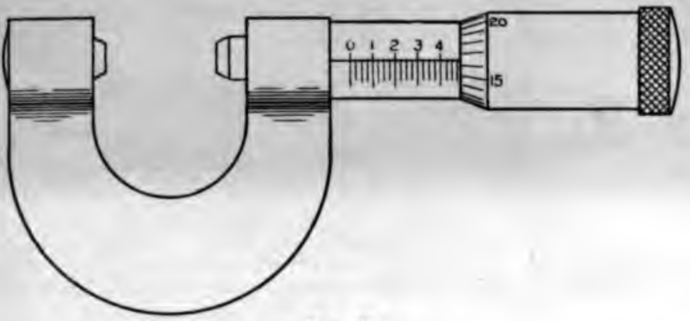


Fig. 25.

Reading the Micrometer. As stated above, the micrometer screw has 40 threads per inch and the thimble has 25 divisions on its circumference. The barrel is divided to correspond to the pitch of the screw with each fourth division numbered. In reading the indicated measurement, first note the highest number visible on the barrel, and call it hundreds of thousands or tenths. (In Fig. 25 it is 400 thousandths or .400.) Then read the short divisions on the barrel, calling the first division 25 thousandths (.025), the second 50 thousandths (.050), and the third 75 thousandths (.075). In this figure the third division is the last one visible. Now read the number indicated on the thimble; that is, the number that has passed the line running lengthwise. In the figure it is 16; or $16\frac{1}{2}$ if the reading is to be finer than thousandths. Add this reading to the readings of the short divisions, thus: $75+16\frac{1}{2}=91\frac{1}{2}$; this is $.091\frac{1}{2}$. Adding the .400 to this we get $.491\frac{1}{2}$. This means that the distance from the anvil to the measuring-point is $\frac{4915}{10000}$ of an inch, or .4915 inch. If the micrometer caliper is a good one, we may be sure the distance is between .491 inch and .492 inch.

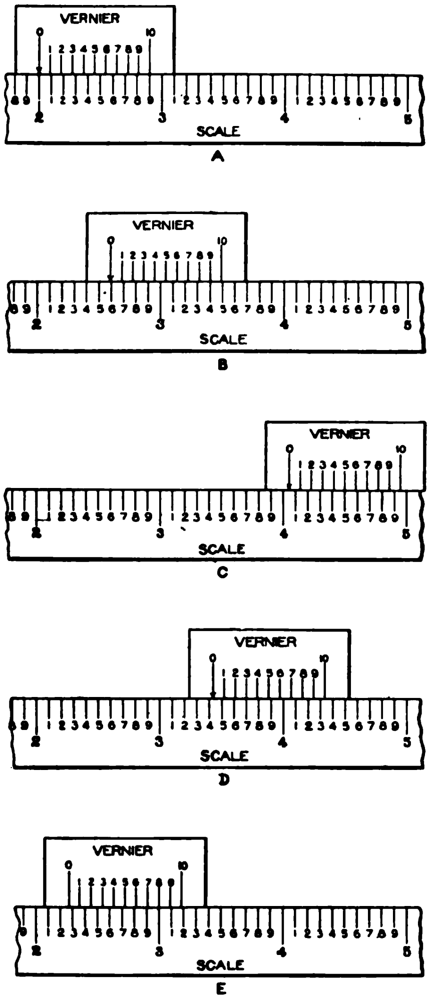


Fig. 26.

The Vernier. As has already been stated, the finest graduation that can be easily read on a steel rule by the naked eye, even after much practice, is one-hundredth of an inch. With the growing refinement in measurements, it was found necessary to obtain readings finer than this, and a method of subdivision, known from the name of the inventor, as the "Vernier," was adopted. The principle will first be explained. (See Fig. 26.)

Let two rules be so graduated that the true scale has each inch divided into ten equal parts, and the Vernier scale has ten divisions occupying the same space as nine of the divisions of the scale. It is evident that one of the divisions on the Vernier is equal to $\frac{9}{10}$ of one of those on the scale. Now, if the Vernier be moved to the right so that the graduations marked

1 shall coincide, the Vernier will have moved one tenth of a division on the scale, or one hundredth of an inch; when graduations numbered 5 coincide, the Vernier will have moved five hundredths of an inch; when lines marked 0 and 10 coincide, the Vernier will have moved nine hundredths of an inch; and when 10 on the Vernier comes opposite 10 on the scale, the Vernier will have moved ten hundredths of an inch, or the whole of one division on the scale. By this means the scale, although graduated only to tenths of an inch, may be accurately set at points whose positions are expressed in hundredths of an inch.

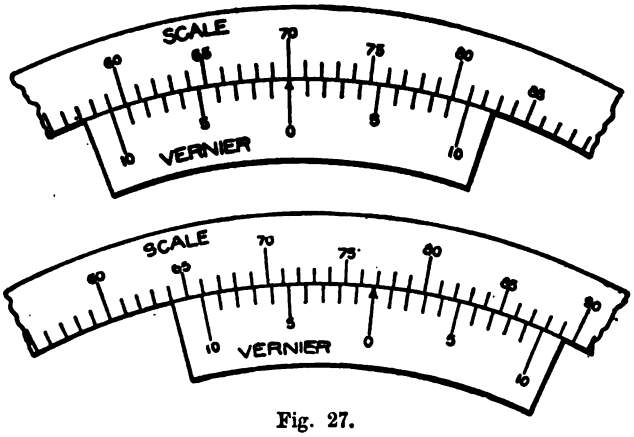


Fig. 27.

Let us consider Fig. 26. At A the Vernier is shown with the 0 in line with 2 on the scale; hence the reading is 2.000.

In B, the 0 of the Vernier has moved to the right beyond the division marked 5. The line 9 on the Vernier is in line with a line on the scale; hence the reading is 2.59.

In C, the zero of the Vernier has moved to the right still farther. The reading is evidently 4.05.

In D, the reading is 3.43.

In E, the reading is 2.28.

While arcs of small radius can be easily graduated into degrees, it is not possible to subdivide the degree without making the divisions confusing. By aid of the Vernier placed just above the true scale representing degrees, readings can be made with accuracy to one-tenth of a degree, or six minutes. The divisions of such a Vernier scale are shown in Fig. 27, and are also shown when set to read 76° 48′.

The most common application of the Vernier to linear measurements is found in the Vernier caliper square. The one shown in Fig. 28 reads to one-thousandth of an inch. Each inch of the true scale, or beam of the instrument, is divided into 40 parts (every fourth graduation being emphasized), while the Vernier, or sliding-scale, has 25 divisions, occupying the same space as 24 divisions on the true scale. By the reasoning used in connection with Fig. 26 the difference in length of one division on the Vernier, as compared with one of those on the true scale, is equal to one twenty-fifth of one fortieth or one thousandth of an inch. The caliper square shown in Fig. 28 is set at .279 inch. The scale is also shown enlarged in which the reading is 1.31 inch.

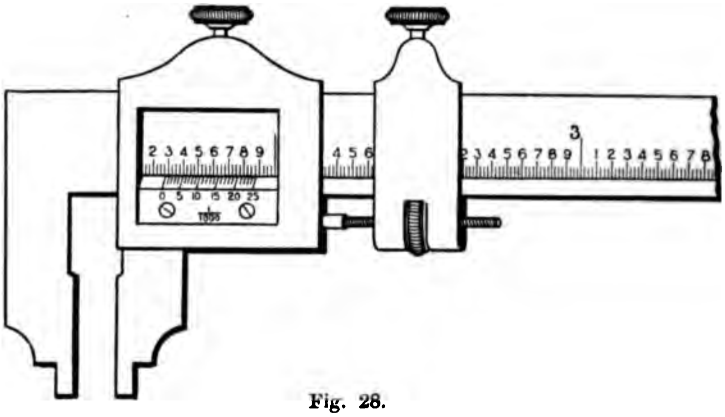


Fig. 28.

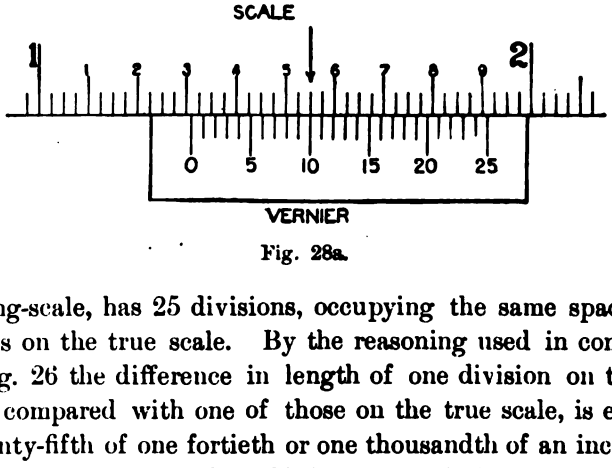


Fig. 28a.

By the use of the Vernier in connection with the micrometer caliper, readings are easily made to one ten-thousandth of an inch.

As shown in Fig. 29, lines are drawn on the barrel parallel to the reference line, making ten equal divisions occupying the same space as nine divisions on the thimble. Referring to Fig. 30, it will be seen that each division on the thimble may be accurately divided into ten parts, each indicating a difference in the position of the measuring point of one ten-thousandth of an inch. Rapid reading of the Vernier in any form can only be acquired by practice, but the following directions may be found helpful:

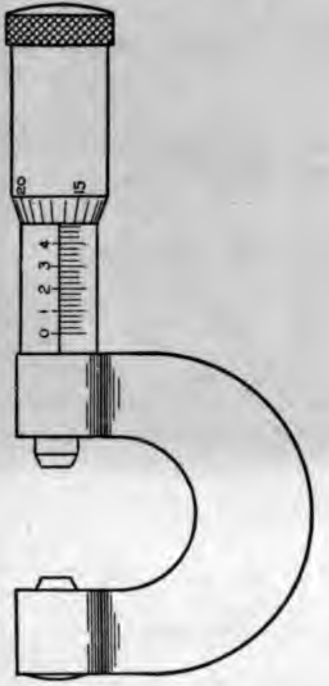


Fig. 25.

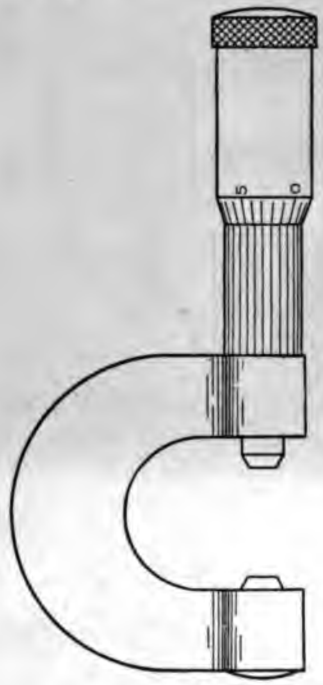


Fig. 29.

In Reading the Vernier, we must bear in mind the fact that each division on the Vernier is $\frac{9}{10}$ of one division on the scale, and that if line No. 1 on the Vernier is in line with any division of the scale the zero of the Vernier is $\frac{1}{10}$ of one division away from the graduation below it; if line No. 2 is in line, the zero is $\frac{2}{10}$ away from the graduation; if line No. 6 is in line, the zero is $\frac{6}{10}$ away.

Suppose the Vernier is in position on the scale and graduated as shown in Fig. 30. First read the highest division on the scale to the left of the zero on the Vernier. (69 is the division in the figure.) Then follow along the scale (to the right) until two graduations are found that are in line, as at 6 on the Vernier and 75 on the scale. Now, since one division on the Vernier means that the zero is $\frac{1}{10}$ of a division of the scale away, six divisions of the Vernier means that the zero is $\frac{6}{10}$ away; hence the zero of the Vernier is $\frac{6}{10}$ beyond the 69, and the reading is 69 and $\frac{6}{10}$ or 69.6.

Arcs of circles, such as are on surveyor's instruments, may be graduated to read to half degrees if the diameter is about 8 inches. Now, if we put on the circle a Vernier graduated so that we have 30 divisions equal to 29 divisions of the scale (arc), we can read 30ths of half degrees or *minutes*.

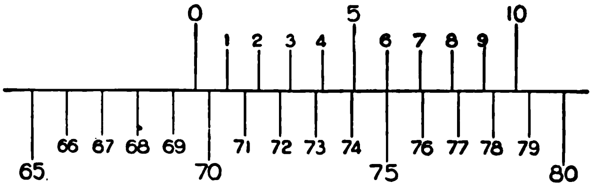


Fig. 30.

Vernier Micrometer. To get very accurate readings, a Vernier scale is placed on the barrel of the micrometer caliper. Let Fig. 29 represent the back side of the micrometer caliper shown in Fig. 25. The reading already obtained was .491 inch. Now turn the caliper over (Fig. 29), and, commencing at the right, count the graduations until one is reached that coincides or is in line with a graduation on the thimble. In doing this, call the first division zero, the second 1, the third 2, etc. The number of the division on the Vernier that is in line with the division on the thimble indicates the ten-thousandths above the regular micrometer reading. From Fig. 29 we see that the 5th line is the graduation which is in line with the division on the thimble which should be called 4, as explained above. Then the reading is .4914 instead of .4915, as we read it from the other side (the plain micrometer). With a good micrometer, we can be sure that the distance between the anvil and the point is more than .4913 and less than .4915.

The Retrograde Vernier. In addition to the direct Vernier, there is another form called the retrograde Vernier, which has 10 divisions on the Vernier and 11 on the scale. In this case the graduations on the Vernier must be reversed, as shown in Fig. 31.

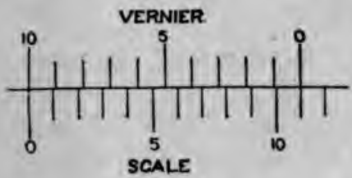
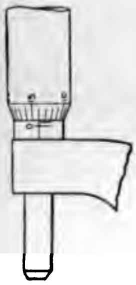


Fig. 31.

Calipers reading to ten-thousandths should not be commonly used when fine measurements are not required, because in an instrument of this class wear is perceptible and important which would be of comparatively little consequence in a caliper that reads only to thousandths.

In using the micrometer caliper for fine measurements, care should be taken in the handling of the instrument. Constant contact with the warmth of the hand will expand it sufficiently to make an error in the reading. The body should be held between the thumb and forefinger of one hand and the thimble turned with the other. It should be laid aside as soon as a reading has been made. It should never be laid upon a piece of cold iron, because the contraction due to chilling is likely to cause an error in the opposite direction from that which would be caused by the heat of the hand.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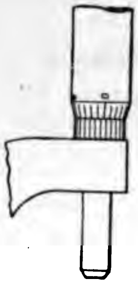
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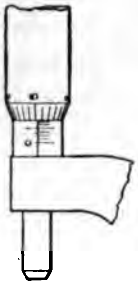
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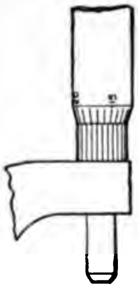

D

EXAMPLES FOR PRACTICE.

1. A micrometer caliper shows a reading of .463 ; how many times must the thimble be turned to produce a reading of .587 ? Assume 40 threads per inch. Ans. $4\frac{24}{25}$ times.

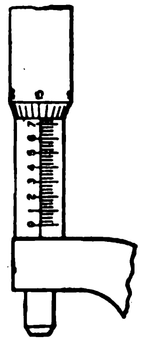
2. What are the readings of the Vernier micrometer calipers shown in Figs. A and B? Ans. .039.

3. State the readings of the micrometer calipers shown in Figs. C and D. Ans. .1546.

4. Give the readings of the Vernier micrometer calipers shown in Figs. E and F. Ans. .7398.

5. Sketch the front and back of a Vernier micrometer caliper when the reading is .6327.

6. What is the reading of the Vernier and scale when in position G? Ans. 6.36.



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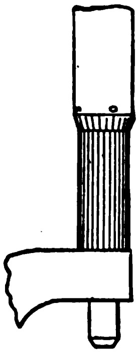

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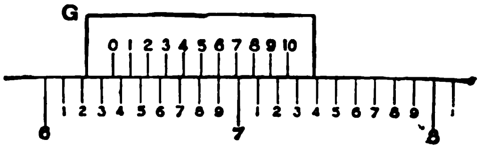


Fixed Gauges. While the adjustable gauges that have just been described are available for a large range of work, gauges of one dimension, or fixed gauges, are used to a considerable extent, especially in shops where work of a duplicate character is produced in large quantities. These may be used as standards to which adjustable gauges may be set, or used directly in connection with the work in the same manner as an adjustable gauge. The form of such gauges for comparisons of length is a steel rod with the ends carefully ground so that the distance required may be quickly and accurately determined. In one form the ends are parallel plane surfaces, and in another the ends are sections of a sphere of the same diameter as the length of the rod. Both these forms are illustrated in Fig. 32. Another form of gauge for the same purpose consists of hardened and ground steel disks, Fig. 33, to which calipers and similar tools may be set, and which may be used also to test the size of holes by direct application. For the latter purpose handles are provided by which the disks can be conveniently manipulated.

Plug and ring gauges, as shown in Fig. 34, furnish accurate and convenient standards for the production of duplicate parts of machines. The same result is attained by the caliper gauge shown in Fig. 35, which combines the two gauges in one piece. In this form the external gauge has parallel plane surfaces and the internal gauge is a section of a cylinder. In sizes above three inches, the caliper gauge is usually made in two parts, also shown in Fig. 35, making the tool easier to handle.

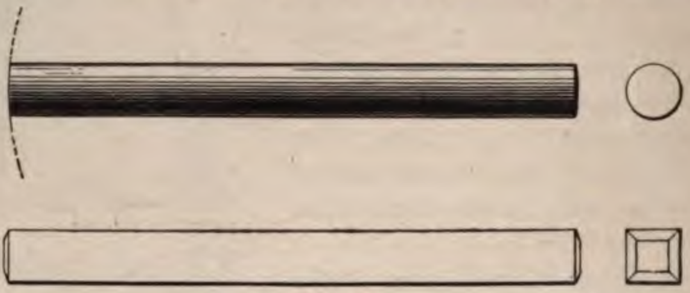


Fig. 32.

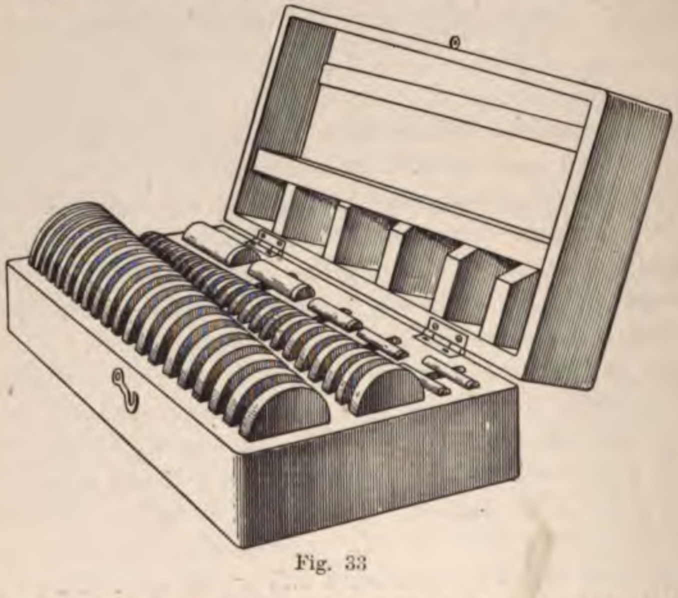


Fig. 33

As is indicated by the cost of these gauges, the exact duplication of such exact sizes in quantities would mean a cost that would be prohibitive in machine construction. The limit of error in the standard gauges just described is never over one ten-thousandth of an inch at a standard temperature, which is usually taken as 70° F. Ordinary machine parts do not require such accuracy,

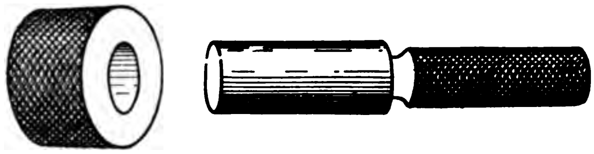


Fig. 34.

and it is usual to allow a limit of error which is in accordance with the class of work being produced.

For testing sizes and dimensions, both at the machine and in the inspection department, combination gauges, known as **limit gauges,** are employed. These are made both for external and

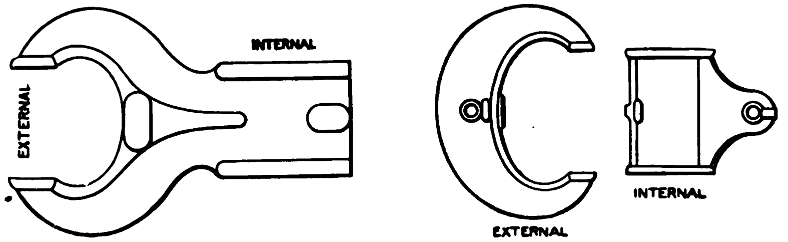


Fig. 35.

internal measurements. The external gauge shown in Fig. 36 is for testing pieces supposed to be .25 inch in diameter. As indicated by the figures on the gauge, the piece is allowed a variation of .0005 inch over, and .001 inch under the nominal size. The words "go on," and "not go on," stamped near the ends, indicate clearly how the gauge is used. This gauge is more conveniently arranged as shown in Fig. 37, in which the work must enter the first parallel opening, but must not pass through the second. In this form, one motion tests the piece for variation above and below the standard. Fig. 38 shows a limit gauge for holes, the end marked "go in" being required to pass into the hole, while the other end, marked "not go in," must not enter. An arrangement of the internal limit gauge similar to the external gauge of Fig. 37 is shown in Fig. 39, and has the same advantages.

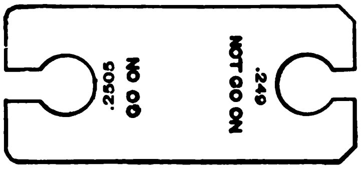


Fig. 36.

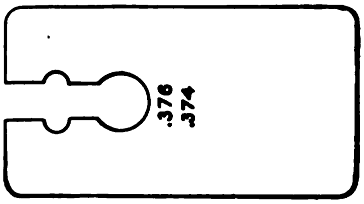


Fig. 37.

In some classes of work, no variation is allowed over the standard, and in others, no variation is allowed under the nominal size. The amount of variation allowed in any case is governed by the class of work and the intended use of the piece. As these allowances are not uniform, such gauges are made only to order.

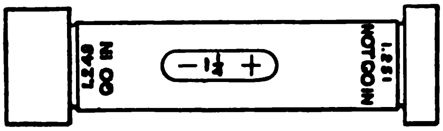
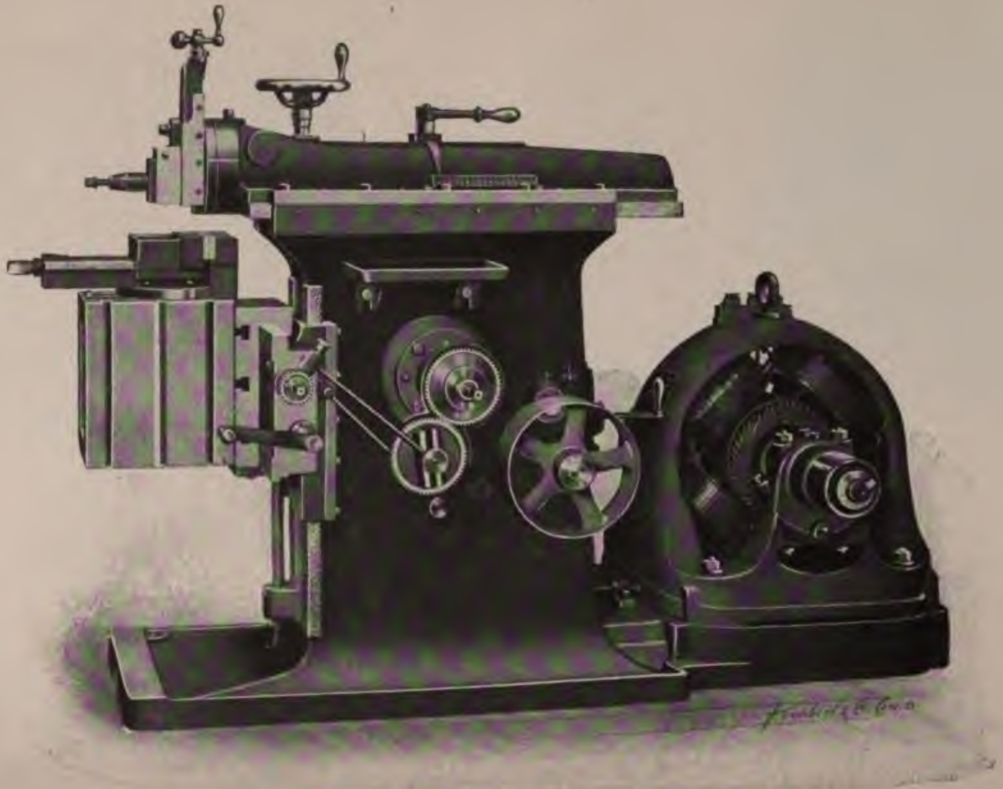


Fig. 38.

For many years gauges of an entirely different character have been used in the measurement of wire, small rods, and sheet metal. The sizes have been designated, not by the diameter or any definite unit, but by a number or letter in a purely arbitrary manner. Even in the same gauge, the sizes do not advance in any regular order. The matter is still further complicated by the fact that in one gauge large numbers indicate large sizes, while in another, the smaller numbers mark the large diameters. Another source of annoyance lies in the fact that such gauges are cheaply made and cannot be relied upon to be duplicates of one another. These gauges were the natural result of the recognition by large manufacturers of the necessity of standards by which to grade their products. Hence we have such gauges as the Brown and Sharpe, Birmingham or Stubs, Washburn and Moen,



CRANK SHAPER. DRIVEN BY VARIABLE SPEED MOTOR.
Cincinnati Shaper Co.

United States standard, Morse Twist Drill Co., and many others. As a step in the right direction, a decimal gauge has recently been adopted, in which the sizes are indicated by numbers which represent the diameters in thousandths of an inch. Most of these gauges had their origin in days when refined measurements were not common, but since the use of the micrometer caliper has become almost universal, there seems to be no good reason why all sizes should not be expressed in thousandths of an inch, thus avoiding all the troubles incident to the use of the arbitrary gauges.

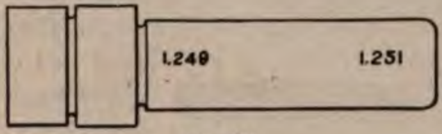


Fig. 39.

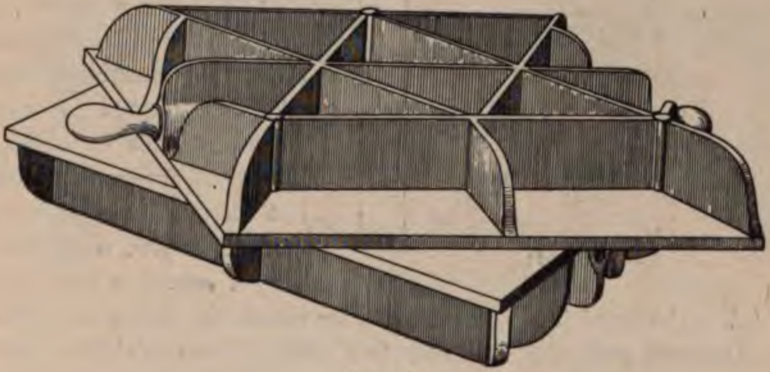


Fig. 40.

For the production of accurate plane surfaces the use of the straight edge is not sufficient. Such surfaces should be compared with standard surfaces called surface plates, Fig. 40. A surface plate is a cast-iron plate strongly ribbed on the back to prevent distortion, and supported on three points to insure a uniform base. The production and use will be described under the head of "Scraping." They may be had in sizes varying from 3 inches by 4 inches to 36 inches by 72 inches.

The machinist's **bench** at which hand work is ordinarily performed should be of substantial character, about two feet ten inches from the floor and two feet six inches wide (see Fig. 41). For the sake of economy it is usual to have a two and one-half or three inch plank at the front to which the vises are fastened and on which all the heavy work is done, while the rear of the bench is made from one-inch stuff. Maple and birch are preferred as materials for a bench, although ash makes a very good substitute.

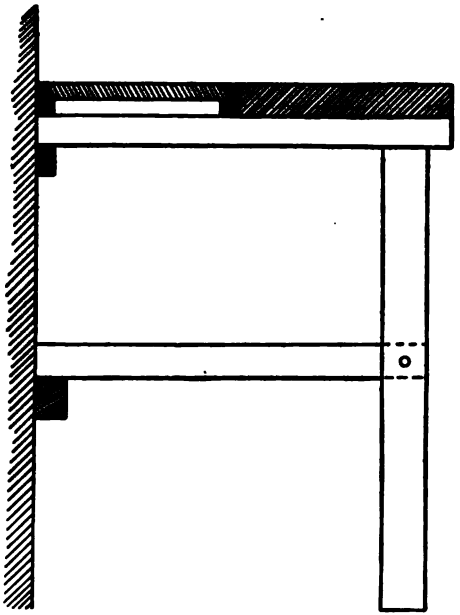


Fig. 41.

In order that work may be held rigidly for the performance of hand operations, the machinist uses what is termed a ***vise.*** They are made in a great variety of forms and sizes, but all consist essentially of a fixed jaw, a movable jaw, a screw, a nut fastened to the fixed jaw, and a handle by which the screw is turned in the nut and the movable jaw brought into position. The sectional view, Fig. 42, shows these parts clearly and also a device, present in some form in all vises, by which the movable jaw is separated from the fixed jaw when the screw is backed out in the nut.

In the machinist's vise, both jaws are made of cast iron with removable faces of cast steel. These may be checkered to provide a firm grip for heavy work, or may be smooth to avoid the marking the surface of the plate operated upon. When holding soft metal, even the smooth steel jaws would mar the surface; and in such cases it is customary to use false jaws of brass or Babbitt metal, or to fasten leather or paper directly to the steel jaws. The screw and handle are made from steel and the nut from malleable iron.

The common method of fastening a vise to the bench is by means of the fixed base shown in Fig. 42, although a swivel base such as is shown in Fig. 43 is preferable. The vise shown in Fig. 43 has a swivel jaw also which enables it to hold tapered work securely. This swivel jaw is provided with a locking-pin which fixes the jaws in a parallel position. The height of the vise from the floor depends somewhat on the class of work to be performed, but a general rule is to have the top of the jaws about one and one-half inches below the point of the elbow when standing erect beside the vise.

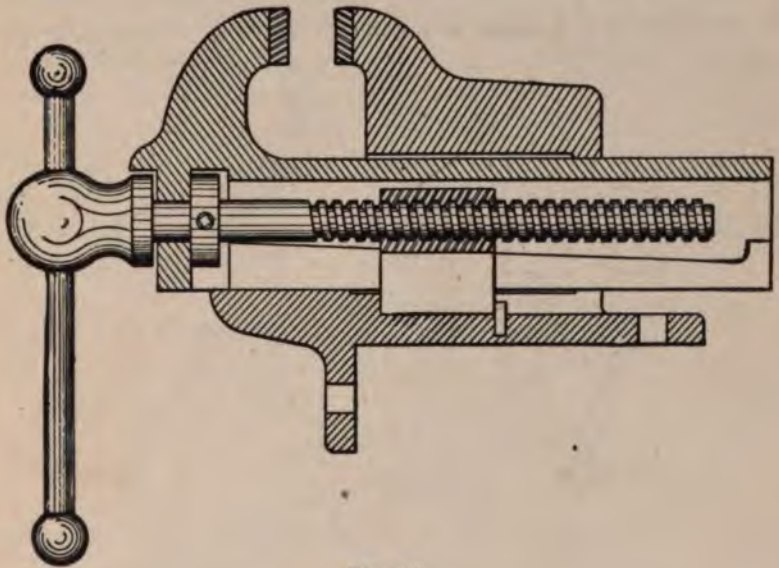


Fig. 42.

CUTTING TOOLS.

The simplest form of metal-cutting tool is the chisel. The several types in common use are shown in Fig. 44. The **flat chisel** is used for snagging castings, for chipping surfaces having less width than the edge of the chisel, and for all general chipping operations. It is the form most commonly used, and is often called the cold chisel. Generally it has a cutting edge about an eighth of an inch wider than the stock from which it is forged. The **cape chisel** is used for cutting key ways, channels, etc., and also for breaking up surfaces too wide to chip with the flat chisel alone. Channels are driven across such a surface, leaving raised portions or "lands" to be removed by the flat chisel. The cutting edge of this chisel is usually one-eighth of an inch narrower than the shank, and the part just in the rear of the cutting edge is made thin enough to avoid binding in the slot. As this weakens the chisel, it is made comparatively thick in the plane at right angles to the cutting edge.

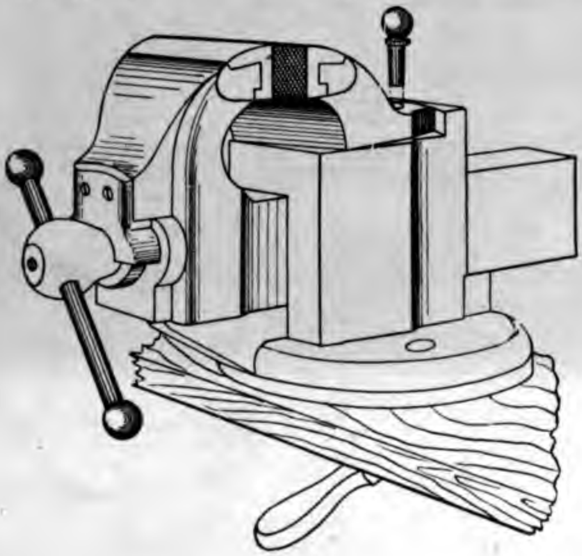


Fig. 43.

The **diamond point** chisel is made by drawing out the end of the stock to about $\frac{5}{16}$ inch square, and grinding the end at an angle with the axis of the chisel, leaving a diamond-shaped point. It is used for drawing holes, making oil grooves, and cutting holes in flat plates.

The **small round-nosed** chisel is cylindrical in section near the cutting end, the edge being ground at an angle of 60° with the axis of the chisel. When used to "draw" the starting of drilled holes to bring them concentric with the drilling circles they are called **center chisels.** This form is also used fo cutting channel, such as oil grooves and similar work. The larger sizes of round-nosed chisels are of the general shape of the cape chisel with one edge rounded, making a convex cutting edge. Large round bottomed channels and all concave surfaces are the proper work of the round-nosed chisel.

All the accompanying forms should be made from a good grade of tool steel, carefully forged, hardened, and tempered to a purple color. The stock generally used is octagonal, and the chisels for heavy work are about eight inches long and three-quarters of an inch in diameter.

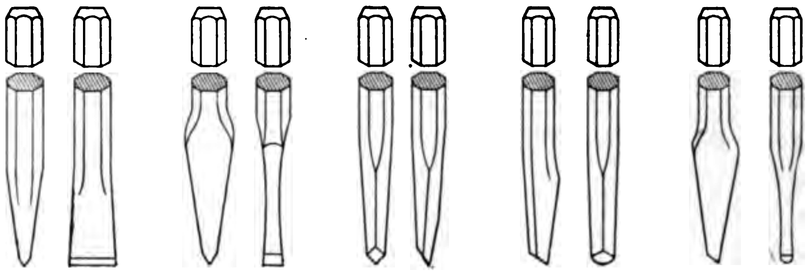


Fig. 44.

The two bevels forming the cutting edge of a chisel should make with each other as small an angle as is possible without leaving the cutting edge weak. If the angle is too small, the chisel will soon become dull, while if large, more force will be required to drive it. The best angle for cutting cast iron, all things considered, is about 70°, while for wrought iron and mild steel a slightly smaller angle, say 60°, will be better. When there are two bevels, they should be alike in width, and form equal angles with the center line of the chisel. Small round-nosed chisels and some slotting chisels are ground one-sided, that is, with but one bevel like a wood chisel. The angle between the surfaces which form the cutting edge should be the same, whether these surfaces are both bevels, or one a bevel and the other the straight side of the chisel. In a one-sided chisel, therefore, the angle that the bevel forms with the center line of the chisel should be twice as large as in one having two bevels.

To cut well, chisels should be sharp, and therefore should be ground at once when they become dull. This may be done on an emery or carborundum wheel, not finer than No. 60, care being taken to avoid heating, which draws the temper, and spoils the tool.

Chipping is a term applied to the removal of metal with the cold chisel and hammer. The degree of accuracy required varies. The piece is held in a vise, and the method of working is to grasp the chisel firmly with the left hand, holding the cutting edge to the work, and striking the head of the chisel with the hammer, keeping the eyes on the edge of the chisel to watch the progress of the work (see Fig. 45). The lower side or bevel of the chisel is the guiding surface, and is held at a very slight angle with the finished portion of the work, the cutting edge only touching. Raising or lowering the shank of the chisel increases or decreases the inclination of the guiding bevel, and causes the chisel to take a heavier or lighter cut. If the hand is carried too low, the chisel will run out before the end of the cut; while if the hand is raised too high, the progress will be slow, owing to the resistance offered by the metal to separation. The depth of the cut taken with a cold chisel should never be more than an eighth of an inch.

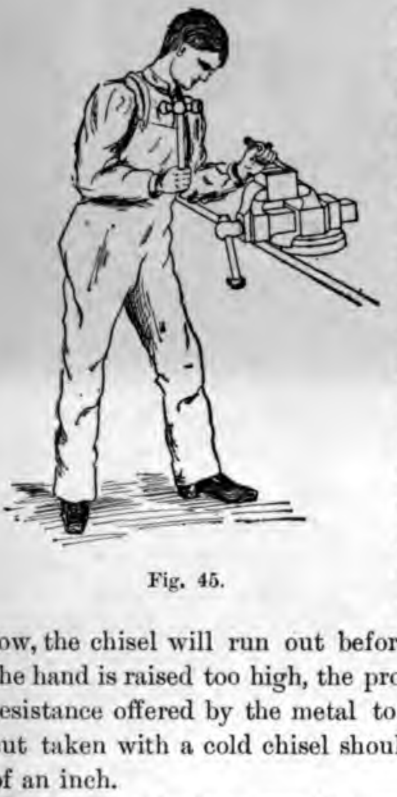


Fig. 45.

When chipping wrought iron or steel, a piece of waste saturated with oil should be kept on the bench, and the edge of the chisel frequently thrust into it. This lubricates the surfaces in contact and preserves the cutting edge of the chisel. While lines are used as guides in chipping operations, it is never advisable to bring the surfaces too near them with the chisel; sufficient stock must be left so that the surfaces may be finished with a file. This is especially to be observed in chipping key ways with a cape chisel; an ample margin for filing should be left, both on the sides and on the bottom.

The **file** differs from the chisel in having a large number of cutting points instead of one cutting edge, and in being driven directly by the hand instead of by the hammer. As hand power only is used, it is evident that the amount of metal removed at one stroke will be small, and the amount removed by a single tooth will be exceedingly small.

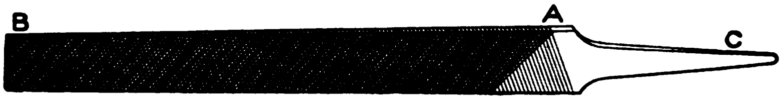


Fig. 46.

Files are made from cast or crucible steel, and in manufacture pass through the successive processes of forging, annealing, grinding, cutting, hardening, and tempering. They have three distinguishing features, viz., length, kind or name, and cut or coarseness of teeth. Length is measured from the heel A to the point B, Fig. 46; the tang C not being included. These lengths vary from three inches to twenty inches.

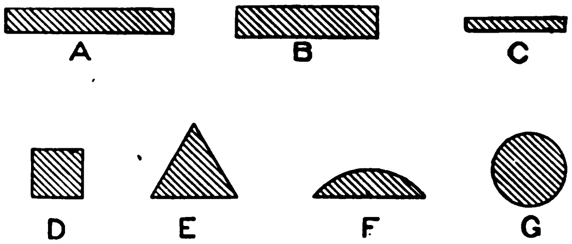


Fig. 47.

There are many kinds manufactured, those in common use being the flat (A), hand (B), warding (C), square (D), three square or triangular (E), half round (F), and round (G), sections of which are shown in Fig. 47.

The cut of files is in two styles, single and double; and each style has several grades of coarseness, viz., coarse, bastard, second-cut, smooth, and dead smooth. The last two grades are sometimes called fine and superfine. As is shown in Fig. 48, the coarseness of each style varies with the length — the longer the file the coarser the cut.

If the cutting surface of a file were perfectly flat, the number of teeth or cutting points engaged with the work would depend on the width of the file and the width of the piece being filed. To force as many cutting points as would be contained in such a large area deeply enough into the metal to enable each to remove its share of the stock, would be beyond the power of the man pushing the file. To avoid this necessity for great pressure, files are usually "bellied" or made slightly convex in the direction of their length, so that, theoretically, the file and the work are in contact only on a line as long as the width of the file. This enables the file to be forced into the metal sufficiently for the teeth to bite, and thus avoids dulling the teeth, which always occurs when the file is allowed to glide over the work without sufficient cutting.

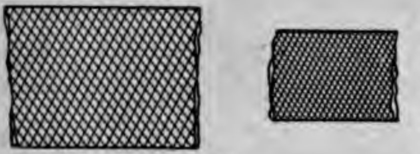


Fig. 48.

This convexity of files also serves another purpose. The pressure applied to the file to make it bite bends the file more or less (see Fig. 49), and if the file in its natural state were perfectly flat, when cutting it would be concave; and this would prevent the production of a flat surface. It would cut away at the edges of the work and leave a convex surface. Such files might, however, be used on convex surfaces.

Work for filing is usually held in a vise such as has already been described, and under ordinary circumstances the surface of the work should be about the height of the elbow. For fine work with small files, where close observation is of more importance than pressure on the file, the work should be higher than this, the height increasing with the refinement of the work. On the other hand, for very heavy filing, where great pressure is absolutely necessary, the work should be several inches below the point of the elbow, so that the weight of the body may be used to good advantage, and also because the workman naturally stoops a little when exerting great pressure on the file.

The handles commonly attached to files are made of wood and are made to fit the hollow of the hand. They are driven onto the tang of the file; a ferrule on the handle preventing it from splitting. Care should be taken to have the axis of the handle parallel with the file. A good way to prepare the handle for the tang is to heat the tang to a dull red, the file proper being kept cool by a piece of wet waste, and the hole in the handle burned out until the tang is almost in the position it is designed to finally occupy. After cooling the tang, very little driving will be required to securely fasten the handle to the file.

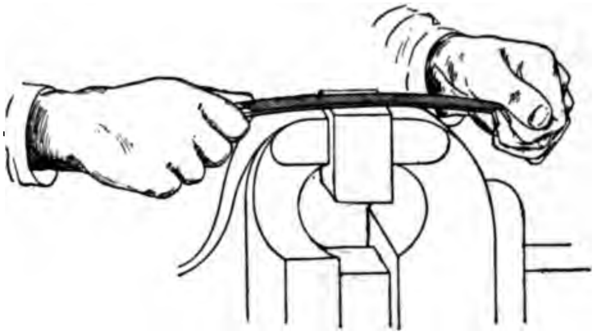


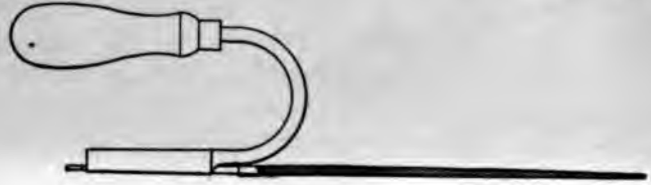
Fig. 49.

When filing surfaces of such size that the handle as ordinarily applied would interfere with the use of the file, the tang may be bent up to an angle so that the handle will clear the surface. Various forms of holders are used for filing under these circumstances; the simplest forms being shown in Fig. 50.

The correct position for filing is about as follows: feet about eight inches apart and at right angles, the left foot being in line with the file; stand back from the vise so that the body may follow the file slightly; grasp the file handle with the right hand, fingers below, thumb on top of the handle; for coarse filing, place the ball of the thumb of the left hand on the point of the file; for fine filing grasp the point of the file with the thumb and forefinger of the left hand. See Fig. 51. When holding the file in one hand, as is often done in light work, the forefinger should be on top of the file pointing in the direction of its length, as is shown in Fig. 52. This allows free movement of the hand and wrist, pressure being applied principally by the forefinger.

As file teeth or cutting edges point toward the end of the file, it is evident that the file can cut only when moving in a forward direction. On the return stroke, the pressure should be relieved; otherwise the teeth will be dulled when drawn back over the surface.

The kind of metal being worked determines in a great measure the character of the file to be used. Cast iron, especially if the scale has not been previously removed, is particularly hard on a new file, as the glassy character of the scale tends to dull the cutting edges. New files should never be used on such a surface. It is found that on tool steel, and hard materials generally, a second-cut file is better than the bastard. This is because if pressure enough is exerted to cause the coarse teeth of the bastard to bite into the work, the teeth, being comparatively long, are very likely to be broken off.. In the second-cut file, the teeth are shorter and present more cutting points in a given area; thus preventing excessive duty being imposed on a few teeth.



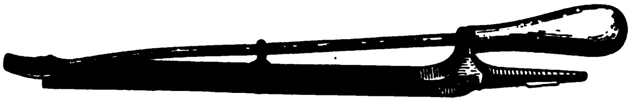


Fig. 50.

Softer metals, such as brass and bronze, allow the use of the coarser grades.

The particles of metal removed by a file frequently remain in the teeth and diminish their cutting qualities. In the case of hard metals these particles, or "pins," often scratch the work. It is necessary, therefore, that files be frequently cleaned. This may be done in a measure by striking the edge of the file lightly against the bench or vise, but it is more effectually performed by using a stiff brush or a piece of card clothing (Fig. 53). In the finest grades of files, a thin piece of wood or sheet brass may be drawn across the surface of the file as shown in Fig. 54, and the filings are removed by the points extending into the file teeth.

When filing cast iron, neither the file nor the work should be allowed to become greasy, as this tends to make the file slide without cutting. In filing steel, however, if the file be oiled or filled with chalk, the pinning of the file is prevented in a large degree, and frequent use of the card or brush is not necessary.

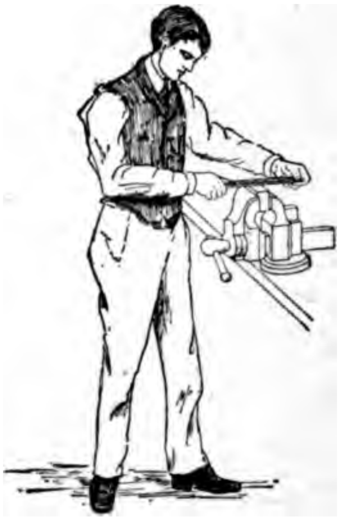


Fig. 51.

What is known as drawfiling is done by grasping the file at each end and moving it sidewise across the work. (See Fig. 55.) The amount of stock removed by this process is usually very small, the object being to lay the file-marks parallel to the length of the work. Single-cut files are better than double-cut for this purpose, being less likely to scratch the work. The remarks concerning cleaning, oiling, and chalking apply both to cross-filing and draw-filing.

No matter how carefully filing is done, it does not leave a surface that is pleasing to the eye, the file-marks are more or less irregular and the whole surface is dull. Exposed parts of machines which are not painted are usually polished. Polishing

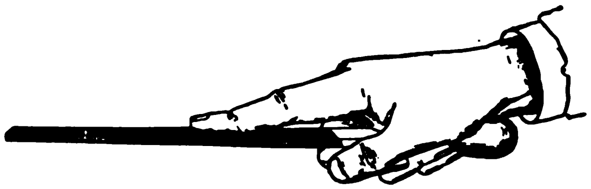


Fig. 52.

does not improve the surface, but simply brightens it and renders it more attractive. As a rule, a polished surface is not a true surface, no care being taken to maintain its truth. In ordinary machine work polishing is usually done by abrasives, such as emery, corundum, and carborundum, while rouge, crocus, rottenstone, and tripoli are used on fine work, especially on brass and composition. Emery, for example, is crushed and sorted into grades varying from No. 8 to flour, the number of the grade indicating the number of meshes per inch in the sieve used in sorting. These grades sometimes bear arbitrary designations, No. 1 indicating a coarse grade and No. 0, 00, 000, 0000 showing the finer grades. These powders are sometimes mixed with oil and applied directly to the work by wooden blocks or clamps; but the more common method is to use what is known as emery cloth, the grains being glued to a strong cloth backing. The finer grades are used on paper in the same manner.

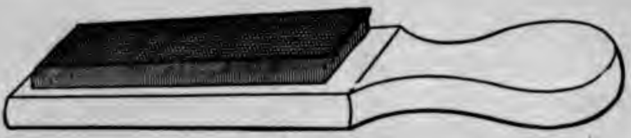


Fig. 53.

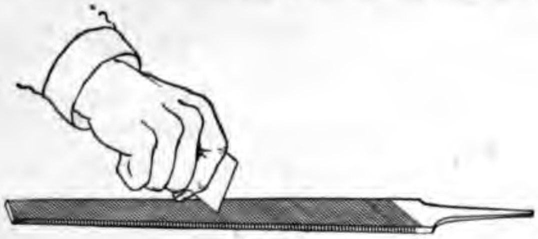


Fig. 54.

Emery cloth is used in many ways; it may be wrapped around a file; folded or tacked to a block of wood; glued to wooden sticks about 15 inches x 1½ inches x ½ inch, fastened around rollers for internal curves, or glued to wooden or steel disks and rotated in a lathe or special machine. In all cases the object is to grind down the surface, using a sufficient number of grades of cloth to produce the degree of polish desired. The marks are laid parallel to each other, making what is known as a "grain." When the process is to be carried to such an extent that no grain is to be visible, the finer polishing agents are used, usually applied with a cloth wheel or "lap." Old cloth does finer work than new, and oil on the cloth will make a finer cut.

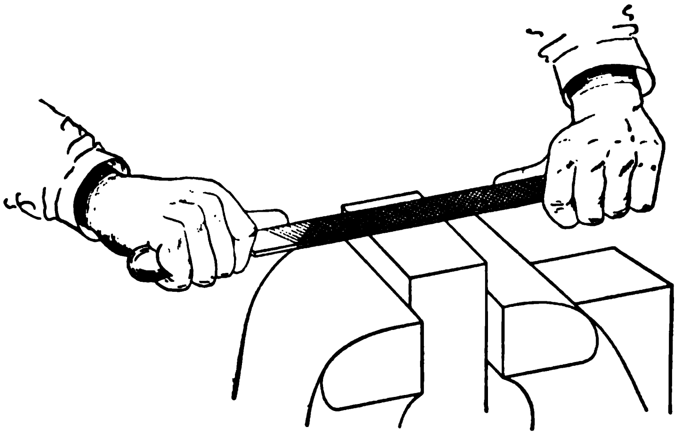


Fig. 55.

Scraping. When two flat or curved surfaces are to be worked together, and complete contact over the whole or both is desired, they are scraped. Scraping removes less metal than filing, and also enables the workman to confine the removal to limited areas. The scraper should be made from a very close-grained tool steel, and is nearly two feet long exclusive of the handle. The general shape is shown in Fig. 56. The cutting edge is about $\frac{3}{32}$ of an inch thick and $1\frac{1}{2}$ inches wide. It is ground on an emery wheel and grindstone, and carefully oilstoned, leaving the cutting edge as straight as possible. Scrapers are sometimes made from old files, the teeth being ground off and the end drawn out wide and thin. Sometimes the end is bent at right angles to the shank, as shown in Fig. 57. The cutting done by scrapers should be perfectly smooth and free from scratches.

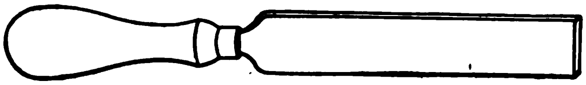


Fig. 56.

In using the surface plate as a test for the truth of a plane, such as a valve or its seat, the plate is covered with a very thin coating of red lead and then rubbed over the valve or seat. The latter should have previously been finished as smoothly as possible. The spots where the red lead shows contact are scraped off, and the process continued until contact over the entire surface is obtained. During the last part of the operation alcohol should be used instead of red lead, as it leaves clean bright spots to indicate where the scraper must be applied. Small pieces of work are rubbed over the surface plate, and in any case care should be taken to distribute the wear uniformly over the plate in order to prolong the truth of the plane. The scraper for concave surfaces, such as boxes, is of the general shape of a half-round file without teeth. In such cases, the shaft to be used takes the place of a surface plate. The method of holding and using such a scraper is shown in Fig. 58.

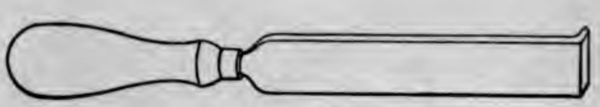


Fig. 57.

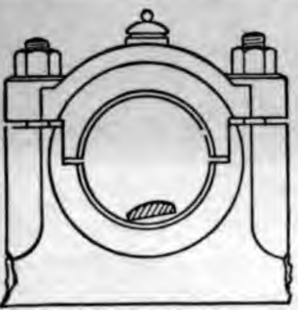


Fig. 58.

Scraping is sometimes done as a matter of finish, and not for the purpose of getting an accurate surface. Therefore, a scraped surface does not always indicate accuracy. Many machine parts are more cheaply finished by scraping than by polishing.

DRILLS.

Drills are of two general classes, the flat and the twist. A **flat** drill of a common type is shown in Fig. 59. The angle between the two cutting edges should be about 110°. These drills are usually made from round tool steel drawn out wide and thin, as shown; the undressed end being used for holding. The flat drill is usually made in the shop where it is to be used. Its low first cost is the principal reason for its existence.

Flat drills made from thin flat stock are used in connection with a slotted rest to start and drill holes in the lathe without previous centering. They are called **chuck-drills.** The end of the shank of the drill is provided with a center hole to receive the dead center of the machine. The drill and rest are shown in Fig. 60.

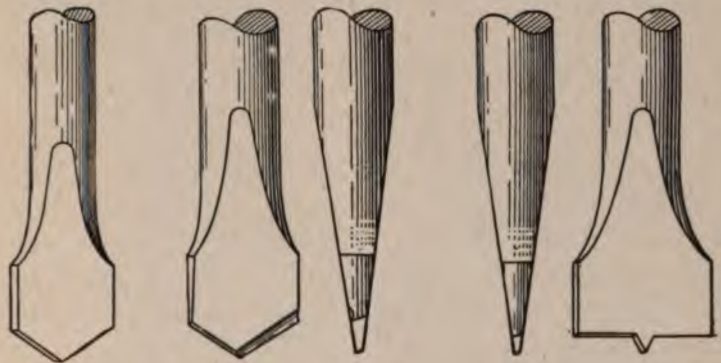


Fig. 59.

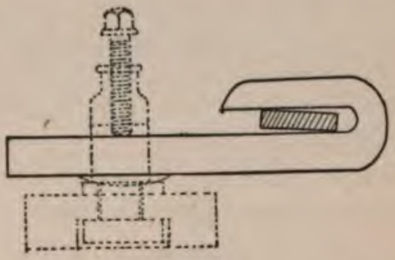


Fig. 60.

The simplest form of **twist drill** is cylindrical throughout its entire length, as shown in Fig. 61, and has two spiral flutes which at the end serve to form the cutting lips, and which also serve to carry the chips from the hole. The included angle of the lips is 118°. This form of drill will work more accurately than the flat drill, as the cylindrical portion serves as a guide to keep the cutting lips in their proper position. The edge being somewhat hooking, removes the metal by a cutting instead of a scraping action as in the flat drill. This form of drill cannot only be fed faster, but can be forced into the work with less power, as it has a tendency, especially noticeable in soft metals, to feed itself into the work. Straight shank twist drills are made from .0185 inch to 2½ inches in diameter; the smaller sizes are sold in sets designated by numbers (1 to 80), letters (A to Z) or fractional sizes (½ inch to $\frac{1}{16}$ inch).

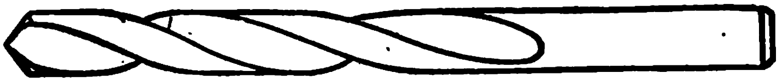


Fig. 61.

The *taper-shank twist drill* is shown in Fig. 62. It consists of a body A, which is fluted and does the actual work, and a taper shank B, by which it is held. This taper fits accurately into the spindle or chuck of the drill press. At the end there is a tongue C, which slips into the key way in the spindle or chuck. As this surface is flat, it serves as a bearing by which the drill is driven. This relieves the tapered portion from the stress of driving by frictional resistance alone. For small drills this frictional resistance is sufficient, but for larger sizes it will not do at all. If for any reason the tongue should become broken, no dependence should be placed upon the frictional resistance of the taper shank to drive the drill. The drill will slip and wear the socket, which will become enlarged and make a misfit for other drills.

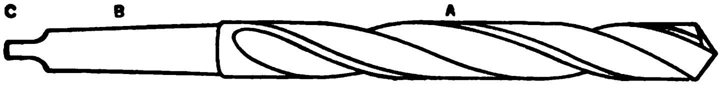
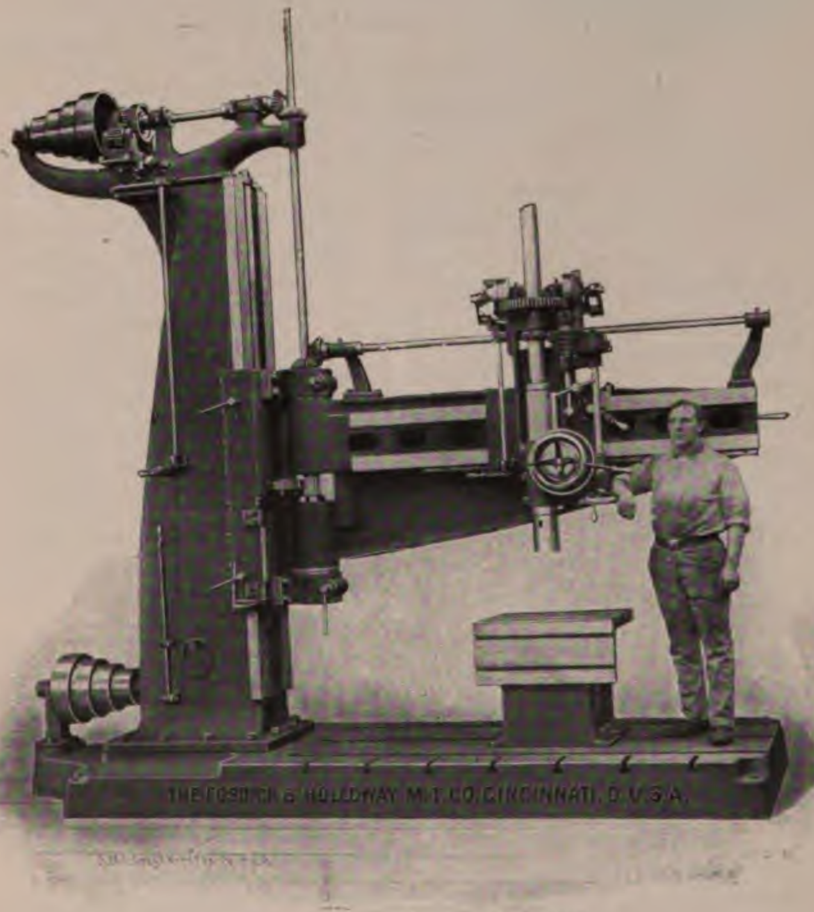


Fig. 62.

The **standard taper** for drill shanks may be considered to be what is known as the Morse. This taper is $\frac{5}{8}$ inch to the foot. There is another known as the Brown & Sharpe or Jarno which has a taper of $\frac{6}{10}$ inch to the foot. No attempt should be made to run the drills of one taper in the sockets of the other.

A flat taper key, introduced into the key way, engages the end of the tongue and serves to remove the drill from the spindle.



EIGHT-FOOT ARM RADIAL DRILL.
Fosdick Mach. Tool Co.

Drills of cylindrical form are also made with straight flutes as shown in Fig. 63. They are used for drilling soft metals, such as brass, especially when the drill passes entirely through the piece. As it breaks through the metal, a drill with spiral flutes tends to draw itself through rapidly, as if it were a screw working in a nut. This may break the drill or move the work from position. Straight flutes give the same cutting action as a flat drill and avoid this tendency to draw.

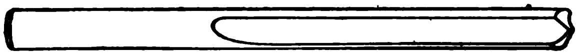


Fig. 63.

Lubrication of Drills. When drilling tough metals such as steel, wrought and malleable iron, heat is generated by the bending or changing of the form of the metal being removed and by friction caused by the chips moving over the lips of the drill. The heating is similar to the heating of a piece of wire bent quickly back and forth. As there is danger of heating the drill to a temperature that will draw the temper and soften the drill, plenty of lard oil, or a mixture of potash and water, should be used. This is not so much for lubrication as to remove the heat.

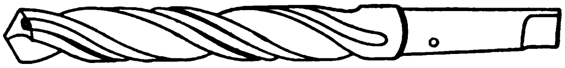


Fig. 64.

Copper is the most difficult to drill of all the common metals on account of its extreme toughness; then, too, copper heats to a higher temperature on account of its low specific heat. Brass does not require the use of oil, and cast iron must always be drilled dry. Particular attention is called to this precaution regarding cast iron.

As the heat is produced at the point of the drill, it is desirable, particularly in the case of deep holes, that the oil be applied directly at the drill point. For this purpose, oil-tube drills, such as is shown in Fig. 64, are used.

The oil is supplied under pressure, and not only removes the heat, but also carries away the chips.

Speed of Drills. The speed at which drills should be rotated depends on the diameter of the drill and the material operated upon. No absolute rule can be given for any one metal or diameter of drill, because of the variation in hardness and tenacity of the material and the condition of the cutting edge of the drill.

The following table of revolutions per minute, given by the Cleveland Twist Drill Co., is based on a peripheral speed of 30 feet a minute for mild steel, 35 feet per minute for iron, and 60 feet per minute for brass.

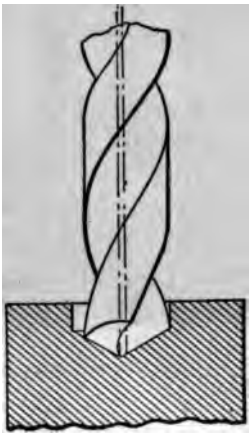


Fig. 65.

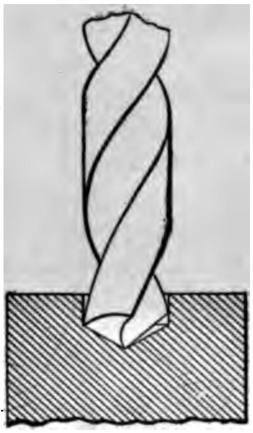
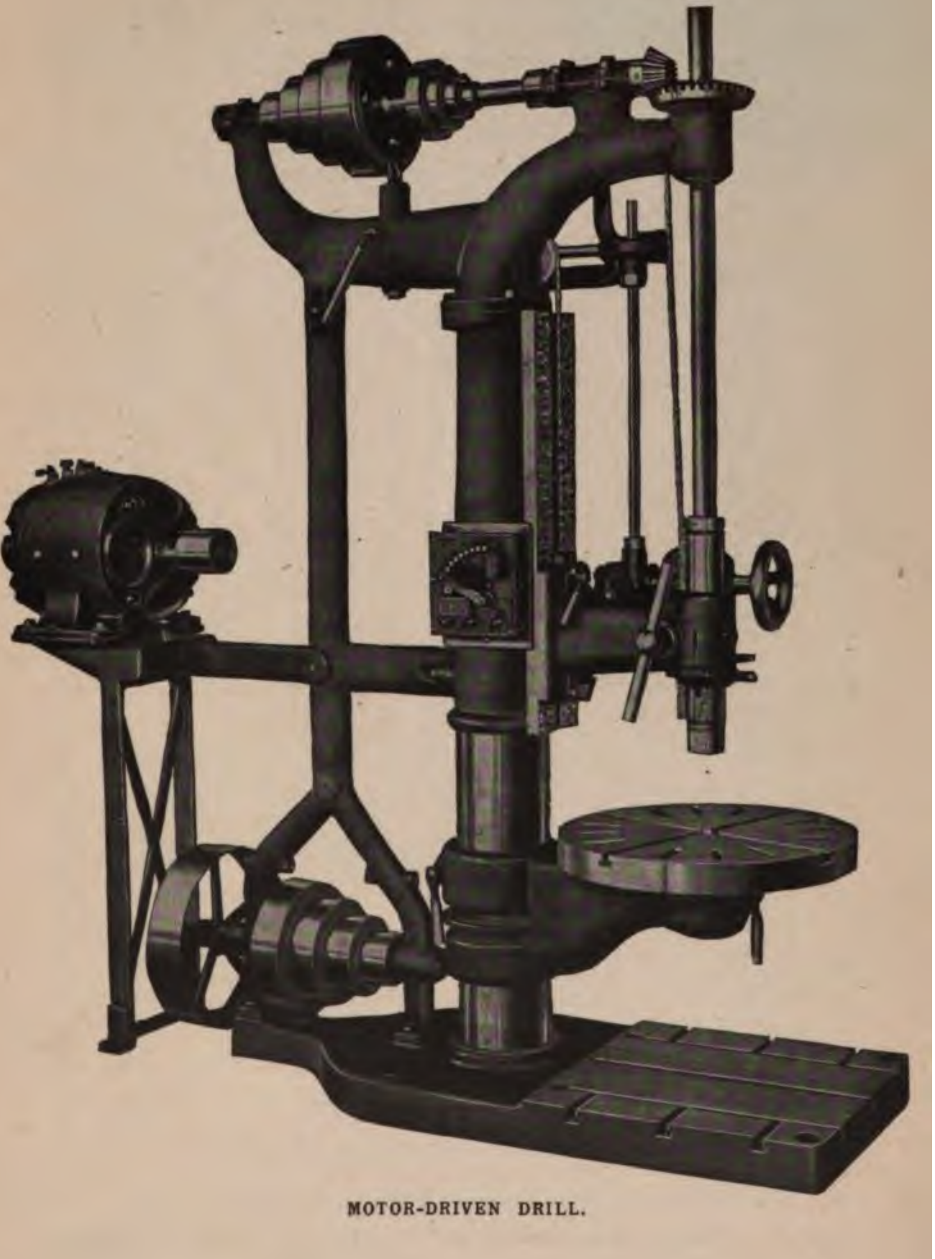


Fig. 66.

The rate of feed also depends on the drill diameter and the material. The above mentioned authority gives, as a maximum, one inch of feed for 95 to 125 revolutions.

Grinding Drills. Great care should be exercised in the grinding of drills. The end of a drill should be symmetrical; that is, the lips should be of the same length, and form the same angle with the axis. If the lips are of unequal length, the hole will be larger than the drill, as is shown in Fig. 65. The point is not in the axis, and the hole will not only be large but also will not be parallel to the drill spindle. If the lips do not form equal angles with the axis, all the cutting will devolve upon the one making the greater angle as shown in Fig. 66. Such a drill will not cut as fast as, and will become dull sooner than, one which is properly ground.



MOTOR-DRIVEN DRILL.

Hand-grinding, especially of twist drills, is neither accurate nor satisfactory; it is much better to do such work on a regular drill grinder built especially for the purpose.

SPEED OF DRILLS.

Diameter of Drill.	Speed for Soft Steel or Wrought Iron.	Speed for Cast Iron.	Speed for Brass.
$\frac{1}{16}$	1824	2128	3648
$\frac{1}{8}$	912	1064	1824
$\frac{3}{16}$	608	710	1216
$\frac{1}{4}$	456	532	912
$\frac{5}{16}$	365	425	730
$\frac{3}{8}$	304	355	608
$\frac{7}{16}$	260	304	520
$\frac{1}{2}$	228	266	456
$\frac{9}{16}$	203	236	405
$\frac{5}{8}$	182	213	365
$\frac{11}{16}$	166	194	332
$\frac{3}{4}$	152	177	304
$\frac{13}{16}$	140	164	280
$\frac{7}{8}$	130	152	260
$\frac{15}{16}$	122	142	243
1	114	133	228
$1\frac{1}{16}$	108	125	215
$1\frac{1}{8}$	102	118	203
$1\frac{3}{16}$	96	112	192
$1\frac{1}{4}$	91	106	182
$1\frac{5}{16}$	87	101	174
$1\frac{3}{8}$	83	97	165
$1\frac{7}{16}$	80	93	159
$1\frac{1}{2}$	76	89	152
$1\frac{9}{16}$	73	85	145
$1\frac{5}{8}$	70	82	140
$1\frac{11}{16}$	68	79	135
$1\frac{3}{4}$	65	76	130
$1\frac{13}{16}$	63	73	125
$1\frac{7}{8}$	60	71	122
$1\frac{15}{16}$	59	69	118
2	57	67	114

While grinding, care must always be exercised that the cutting edge is not overheated on the stone or emery wheel. If it is overheated, the temper will be drawn and the drill become too soft to properly do its work. The angle between the front face of the drill and the bottom of the lip may be from 70 to 80 degrees. This will give ample clearance for the bottom of the drill and leave sufficient metal to support the cutting edge.

REAMERS.

It is difficult, if not quite impossible, to drill a hole to an exact nominal diameter. For most work, a variation of a few hundredths of an inch from the nominal diameter is of no account. Where greater accuracy is required the holes are reamed; that is to say, the hole is first drilled somewhat smaller than it is desired, and is then reamed out to the proper size with a reamer.

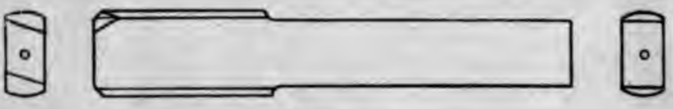


Fig. 67.

Holes drilled with the flat chuck drill mentioned above are usually $\frac{1}{16}$ inch under the finish size. A flat chuck reamer, Fig. 67, is used to enlarge the hole to within about .005 inch of the true size. This reamer is centered on both ends and turned to size.

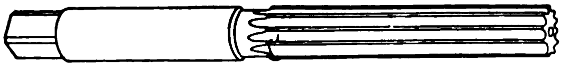


Fig. 68.

The entering rod, which does the cutting, is given a short, sharp taper, while the straight portion serves as a guide to keep the tool in position. By this means the drilled hole is straightened and brought close to size.

To give the hole a smooth surface and correct diameter, a fluted reamer (of which there are various forms) is used. This tool is not intended to remove large amounts of metal, but serves only to increase the size of a hole by a small fraction of an inch up to the diameter required. The hole should not be more than $\frac{1}{64}$ inch smaller than the reamer; this will leave $\frac{1}{128}$ inch on each side for the reamer to cut. If possible, it will be better to drill the hole even nearer than this to the required diameter.

It is evident that if the reamer were to be made of the same diameter throughout its whole length, it would be very difficult to make it enter the hole. In order to facilitate this, it is usually made slightly tapering, for a distance from the entering end, equal to about one diameter.

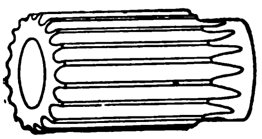


Fig. 69.

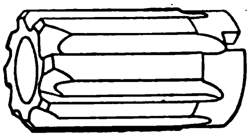


Fig. 70.

One form of reamer has a shallow screw thread cut at the entering end. This thread takes hold of the metal and draws down into the work. When using a reamer, it is always well to pass the entire tool through the hole. The leading end is subjected to the greatest amount of wear because it does the greatest amount of work. If, therefore, only the leading end is put through, the hole will not be of a uniform diameter throughout. Oil should always be used on reamers when they are working in wrought iron or steel.

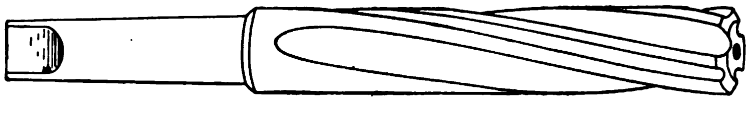


Fig. 71.

The hand reamer, Fig. 68, is the typical form, and one which can be used in many cases in place of special forms. Fig. 69 is better adapted for use in the lathe than the hand reamer. This may follow the flat chuck reamer to finally finish a hole.

In reaming cored holes, the cylindrical chuck reamer, sometimes called the roughing reamer, is often used. It is made either rose, Fig. 70, fluted, or with three spiral flutes, Fig. 71, and generally have solid shanks. The last-named style will finish very smooth and close to size when started true by preliminary boring.

A solid reamer cannot be sharpened without reducing its diameter; therefore, it must be used carefully in order to prolong its life. Reamers with adjustable blades meet this objection, but cost much more than the solid form. An expanding reamer, Fig. 72, can be slightly enlarged to compensate for grinding, and is then used as a solid reamer. Fig. 73 shows an adjustable reamer with inserted teeth.

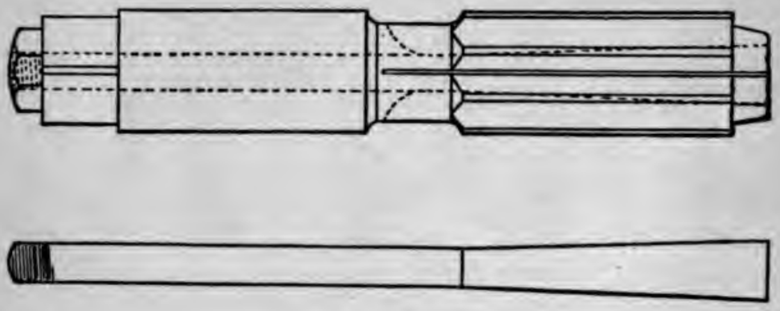


Fig. 72.

Reamers are made for tapered as well as for straight holes. The angle varies with the intended use of the taper; for example. the *locomotive taper* of $\frac{1}{16}$ inch per foot is intended for bolt hole where plates are to be drawn solidly together and the holes completely filled. It is very difficult to remove a bolt from a hole, with such a slight taper. When pieces are pinned together, such

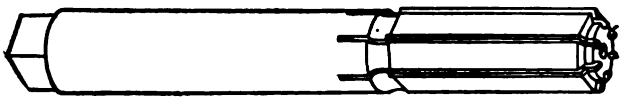


Fig. 73.

as a hub to a shaft, it is intended that they can be separated when desired, so the taper is made steeper, generally ¼ inch per foot. This has come to be known as the *pin taper*. Taper holes for holding lathe centers and taper shank twist drills are generally made ⅝ inch per foot (*the Morse taper*). This angle holds the tool firmly, and still it can be easily removed. The three tapers mentioned are recognized as standard, and reamers for them are carried in stock. Of course many other tapers are used by different manufacturers, but they are regarded as special. Fig 74 shows taper reamers.

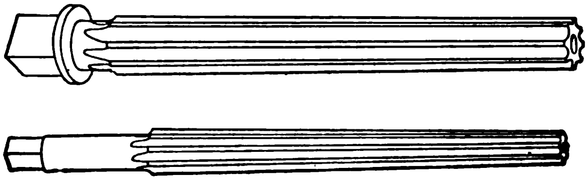


Fig. 74.

Taper reamers differ from hand reamers only in the angle and by not requiring the tapered entering end.

Holes to be reamed by taper reamers must be slightly larger than the small end of the reamer; and, if the hole is deep, it is usual to make a stepped hole, shown exaggerated in Fig. 75, by using drills of different diameters.

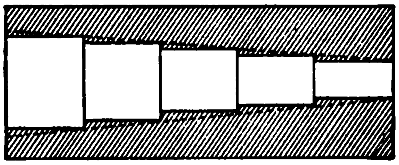


Fig. 75.

When not carefully sharpened, all forms of reamers have a tendency to chatter and produce rough surfaces. To avoid this, the flutes are frequently irregularly spaced; another method is to use spiral flutes, usually left hand.

TAPS.

When internal thread cutting is done, the tool is called a tap. There are many styles of taps; the names in some cases are suggested from the shape, but more often from the use. In most machine shops are found the following forms: hand, machine screw, pipe, pulley, stay-bolt, boiler, and tapper; of these the hand and machine screw are the most common. The object of all is to make spiral grooves, called threads, in holes, so that they may receive and hold screws, bolts, studs, etc.

As the size of a tap is the diameter outside the threads, it is evident that the hole drilled for tapping must be smaller than the tap by nearly, if not quite, twice the depth of the thread. The shape of the thread partly determines the amount to be subtracted from a tap diameter. There are now recognized as standard, five different threads, viz.: sharp or V, Franklin Institute or United States standard, Whitworth, International or metric, and the 29° or Acme. These shapes will be described and compared under Screw Cutting. The following table shows the diameters of the holes that are to be drilled for cutting the various sizes of the threads according to the United States standard and the ordinary V-thread.

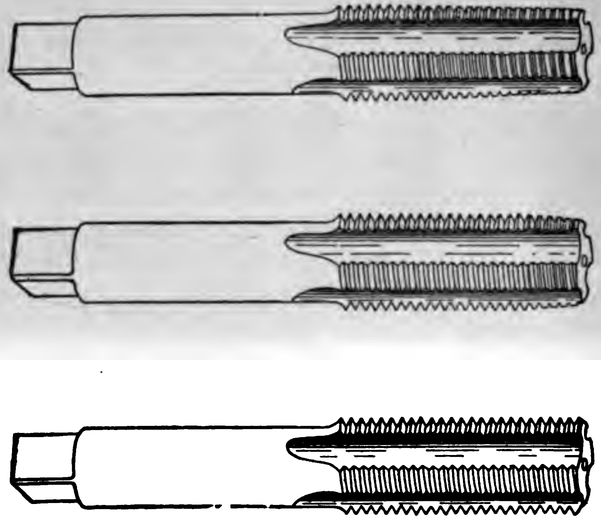


Fig. 76.

Hand taps are most commonly used in shop practice, and a description of the operation will answer for all styles. They are usually sold in sets of three, — taper, plug, and bottoming. See Fig. 76.

The cutting of a thread with a tap is not difficult, but requires care in the manipulation. The tap does not need to be forced into the work, since the thread will draw it forward. The tapering of the tap has a two-fold effect. No one thread must do all of the work in the removal of the metal; each succeeding thread removes a small amount until the full thread has entered the hole. The second effect is that, as in the cases of a reamer, the tap is easily entered and started. Care must always be exercised at this point of the work. The taper of the tap allows it to easily enter the hole, and also makes it possible for it to enter at an angle. If

TABLE OF TAPS AND CORRESPONDING DRILLS.

Tap. Diameter in Inches.	No. Threads per Inch.	U.S. Standard Drill Diameter.	V-Thread Drill Diameter.	Tap. Diameter in Inches.	No. Threads per Inch.	U.S. Standard Drill Diameter.	V-Thread Drill Diameter.
$\frac{1}{4}$	20	$\frac{3}{16}$	$\frac{11}{64}$	$1\frac{7}{8}$	5	$1\frac{5}{8}$	$1\frac{17}{32}$
$\frac{5}{16}$	18	$\frac{1}{4}$	$\frac{15}{64}$	2	$4\frac{1}{2}$	$1\frac{23}{33}$	$1\frac{21}{32}$
$\frac{3}{8}$	16	$\frac{9}{32}$	$\frac{9}{32}$	$2\frac{1}{4}$	$4\frac{1}{2}$	$1\frac{31}{32}$	$1\frac{7}{8}$
$\frac{7}{16}$	14	$\frac{11}{32}$	$\frac{21}{64}$	$2\frac{1}{2}$	4	$2\frac{3}{16}$	$2\frac{3}{32}$
$\frac{1}{2}$	13	$\frac{13}{32}$	$\frac{25}{64}$	$2\frac{3}{4}$	4	$2\frac{7}{16}$	$2\frac{11}{32}$
$\frac{9}{16}$	12	$\frac{7}{16}$	$\frac{7}{16}$	3	$3\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{1}{2}$
$\frac{5}{8}$	11	$\frac{1}{2}$	$\frac{1}{2}$	$3\frac{1}{4}$	$3\frac{1}{2}$	$2\frac{7}{8}$	$2\frac{3}{4}$
$\frac{11}{16}$	11	$\frac{9}{16}$	$\frac{9}{16}$	$3\frac{1}{2}$	$3\frac{1}{4}$	$3\frac{1}{8}$	$2\frac{15}{16}$
$\frac{3}{4}$	10	$\frac{5}{8}$	$\frac{19}{32}$	$3\frac{3}{4}$	3	$3\frac{5}{16}$	$3\frac{3}{16}$
$\frac{13}{16}$	10	$\frac{21}{32}$	$\frac{21}{32}$	4	3	$3\frac{9}{16}$	$3\frac{7}{16}$
$\frac{7}{8}$	9	$\frac{23}{32}$	$\frac{45}{64}$	$4\frac{1}{4}$	$2\frac{7}{8}$	$3\frac{13}{16}$	$3\frac{11}{16}$
$\frac{15}{16}$	9	$\frac{3}{4}$	$\frac{49}{64}$	$4\frac{1}{2}$	$2\frac{3}{4}$	4	$3\frac{7}{8}$
1	8	$\frac{27}{32}$	$\frac{13}{16}$	$4\frac{3}{4}$	$2\frac{5}{8}$	$4\frac{1}{4}$	$4\frac{1}{16}$
$1\frac{1}{8}$	7	$\frac{15}{16}$	$\frac{29}{32}$	5	$2\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{4}$
$1\frac{1}{4}$	7	$1\frac{1}{16}$	$1\frac{1}{32}$	$5\frac{1}{4}$	$2\frac{1}{2}$	$4\frac{3}{4}$	$4\frac{1}{2}$
$1\frac{3}{8}$	6	$1\frac{7}{32}$	$1\frac{1}{8}$	$5\frac{1}{2}$	$2\frac{3}{8}$	5	$4\frac{3}{4}$
$1\frac{1}{2}$	6	$1\frac{9}{32}$	$1\frac{15}{64}$	$5\frac{3}{4}$	$2\frac{3}{8}$	$5\frac{1}{4}$	5
$1\frac{5}{8}$	$5\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{5}{16}$	6	$2\frac{1}{4}$	$5\frac{1}{2}$	$5\frac{1}{4}$
$1\frac{3}{4}$	5	$1\frac{1}{2}$	$1\frac{13}{32}$				

it is started in the latter condition, the thread will not be at right angles to the surface. The degree of care needed in the starting of the tap depends upon the job that is to be done. In the case of tapping a nut, it will usually be quite sufficient to set the tap by the eye. In finer classes of work, however, the tap should be set with a square. Start the tap into the hole, and place a square on the surface beside it in two positions at right angles to each other, and see that the tap stands parallel to the vertical blade.

When holes have been drilled that are to be tapped, a good way of setting the tap is to put a center in the drill spindle. Put the tap into the hole, and bring this center down into the center hole in the head of the tap; this will steady the latter while it is being started.

In using the tap, it is well to work it back and forth. This allows the chips to work clear of the cutting edges, and the oil to cover them. In case of heavy work, it is possible to drive the tap with the drill spindle, but when thus driving a tap in a machine, the backing up is impossible.

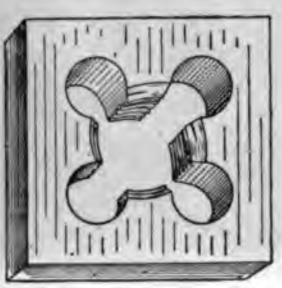


Fig. 77.

Sometimes a thread is to be cut down to the bottom of a hole that does not pass entirely through the metal. In this case the bottoming tap is used. This is a tap that is not tapered at the entering end. The method of working is to first cut the thread as far as possible with the plug tap, and then use the bottoming tap, which will then enter easily and can be driven to the bottom.

Machine tapping is best done by using a frictional tap-holder; that is, one in which the friction is enough to cut the threads, but which will slip when the tap strikes the bottom of the hole. This will insure the hole being tapped to the bottom, and avoid all danger of breaking the tap. To withdraw the tap, the machine is reversed, usually at a higher speed than used in tapping.

When tapping wrought iron and steel, a plentiful supply of oil should be used. On brass the use of oil is unnecessary, while cast iron should always be tapped dry.

DIES.

Dies are used for cutting threads on bolts and other similar parts to be placed in holes which have been threaded by taps.

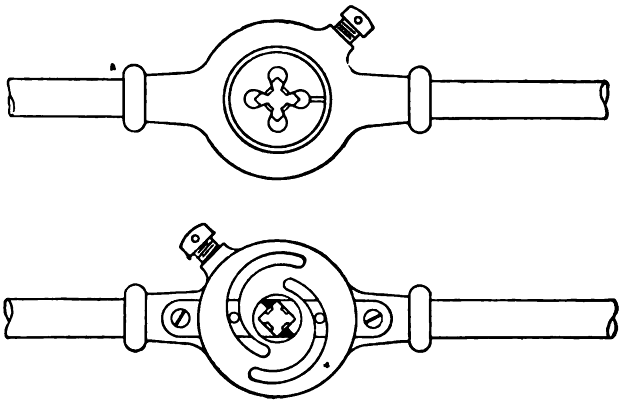


Fig. 78.

The general rules given for the use of taps apply to dies. As the number of threads in a die is much less than on a tap, and because the chips have a much freer exit, it is not as necessary to back up a die as it is a tap.

Dies for small work are usually made solid, as shown in Fig. 77, and often have a slight adjustment for altering the size. They cannot be sharpened, but have an advantage in readily centering on the work. As the full thread is cut at one passage of the die, it takes considerable power to operate solid dies of large size. For this reason, hand-operated solid dies are seldom used above one-half inch. The holder or die stock shown

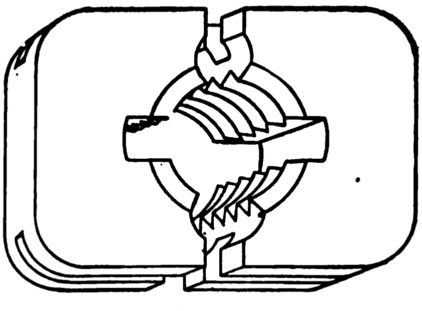


Fig. 79.

in Fig. 78 has a guide to hold the work at right angles to the die, but die stocks are often made without this convenience.

The split form of die, generally known as the jamb-die (shown in Fig. 79), can be easily sharpened, has unlimited adjustment for size, and cuts the thread by easy stages, as it were.

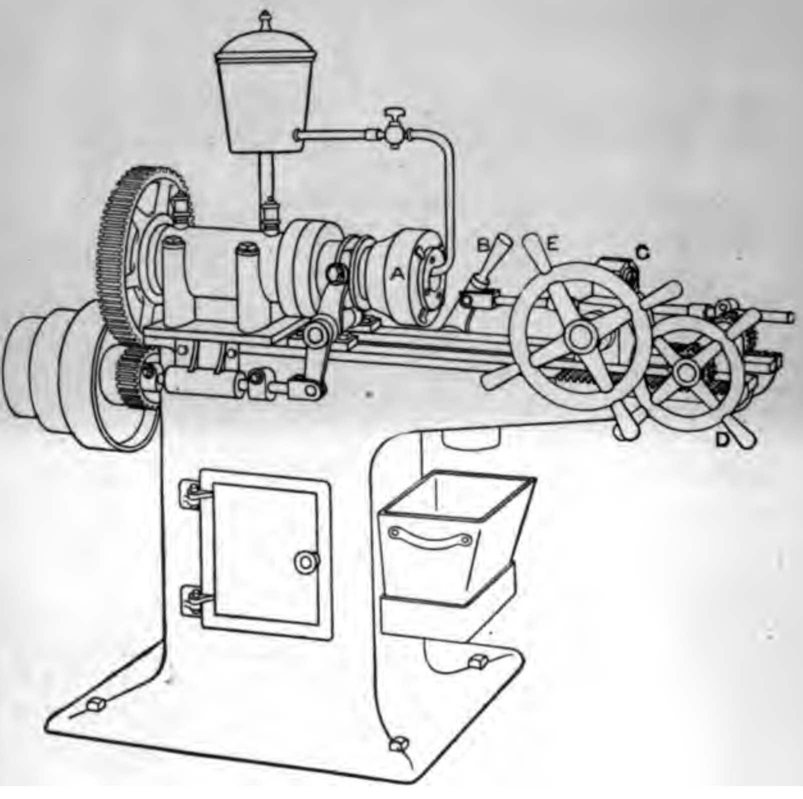


Fig. 81.

It is made in sizes up to two inches, and is for hand operation only. The holder for this form of die is called a screw plate, Fig. 80. These are not furnished with guides for the work.

Cutting Pipe Threads. Another common form of thread cutting is that on wrought-iron pipe. The pipe thread is rounded slightly at top and bottom, and is made tapering at the rate of three-quarters of an inch per foot. The dies are usually solid, square in form, and the die stocks are provided with a ring, which fits over the pipe and serves to hold it square with the die. This avoids the danger of cutting the thread at an angle with the pipe axis.

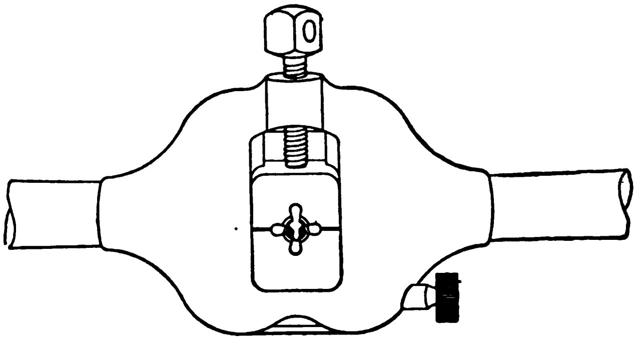


Fig. 80.

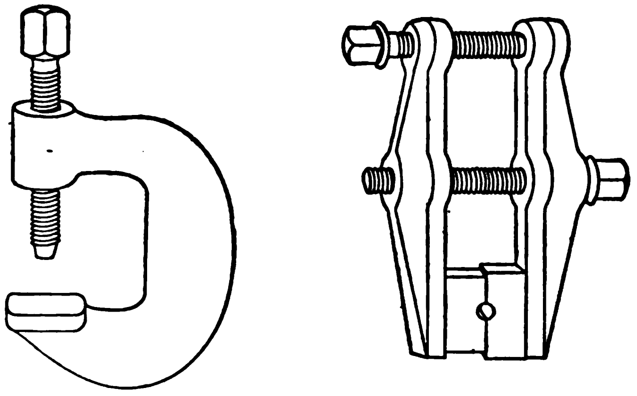


Fig. 82.

Comparatively little thread cutting is done by hand. A large proportion of all such work is performed on bolt-cutters. This is ordinarily the roughest and cheapest class of work, and the running of the bolt-cutter is usually the first work to which the apprentice is assigned.

Bolt-Cutter. An ordinary type of bolt-cutter is shown in Fig. 81. The dies are held in the head A. Instead of being solid, as in Fig. 77, they are made in sections, and can be opened or closed by the movement of the lever B. A chuck, C, is placed on a traveling head, and this can be moved back and forth by the hand-wheel D. The method of working is very simple. The dies in the head are closed in order to be in the working position. The bolt to be cut is gripped in the chuck by turning the handle E, and forced against the dies by the handle D. As soon as the dies have taken hold, they draw the bolt ahead. When a sufficient length of thread has been cut, the dies are opened and the bolt withdrawn. This avoids the necessity of backing out, as would be required if the dies were solid. While the thread is being cut, the dies are kept flooded with oil.

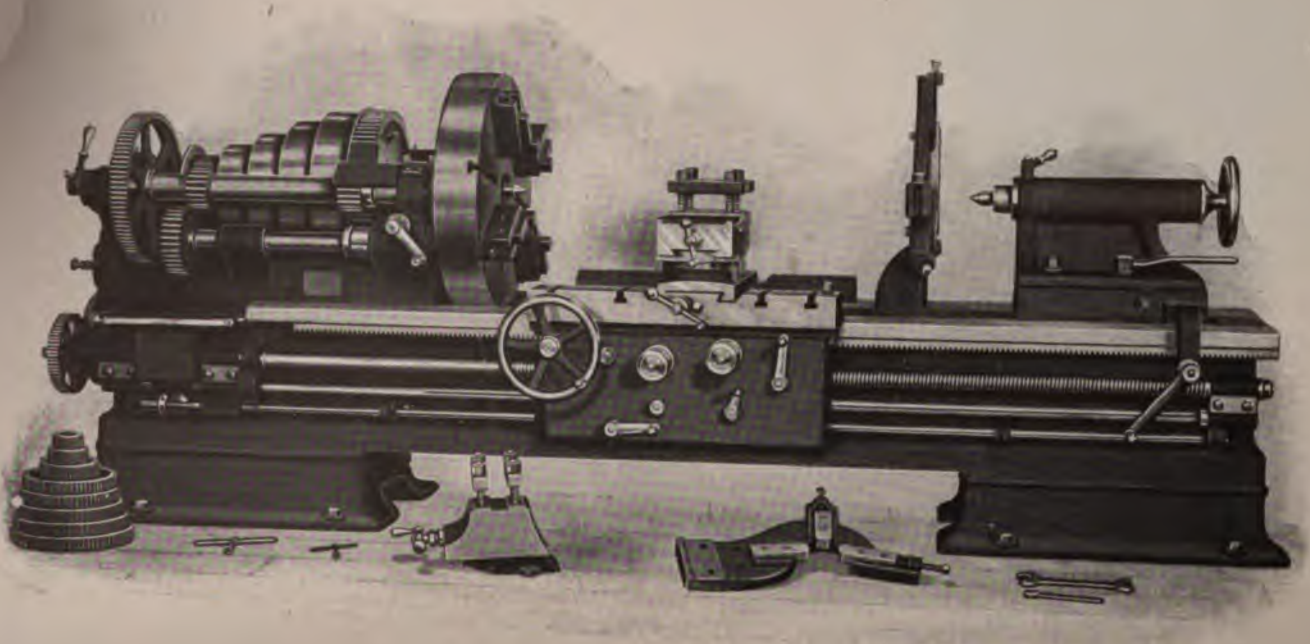
Templets. Where the same piece of work is to be many times repeated, templets are used. This method avoids the necessity of making measurements in the laying out of the work.

The *marking templet* consists of a piece of the same shape as the finished article. It is usually laid on a flat surface, and held fast by iron clamps as shown in Fig. 82. The outline is then marked on the surface with a scriber, and sometimes emphasized by prick punch marks.

The *filing templet* is of the same character as the one just described, but it is hardened. It is clamped in the vise with the piece to be shaped, and the surface filed down to coincide with the form of the templet.

Where holes are to be drilled in duplicate, a templet known as a *jig* is used. These jigs are made so that they fit over the piece to be drilled, and, when clamped in position, indicate the location of the holes by means of hardened steel bushings set in the templet.

The making of templets and jigs is one of the finest branches of the machinist's work, and is generally classed under the head of tool making. The rapid and economical production of machine parts in quantity depends largely on the tool maker, who must, therefore, be considered the highest type of machinist.



32'' x 12' TRIPLE-GEARED LATHE.
Hamilton Machine Tool Company.

MACHINE SHOP WORK.

PART II.

THE LATHE.

THE lathe is one of the most ancient of tools, and is a development of the potter's wheel. The spindle is horizontal and the work is revolved while the cutting tool is stationary. In its various forms and sizes it is by far the most important tool in the machine shop. It is built in a wide range of sizes from the delicate instrument suitable for the work of the jeweler to the great machine capable of turning engine shafts for the largest ocean

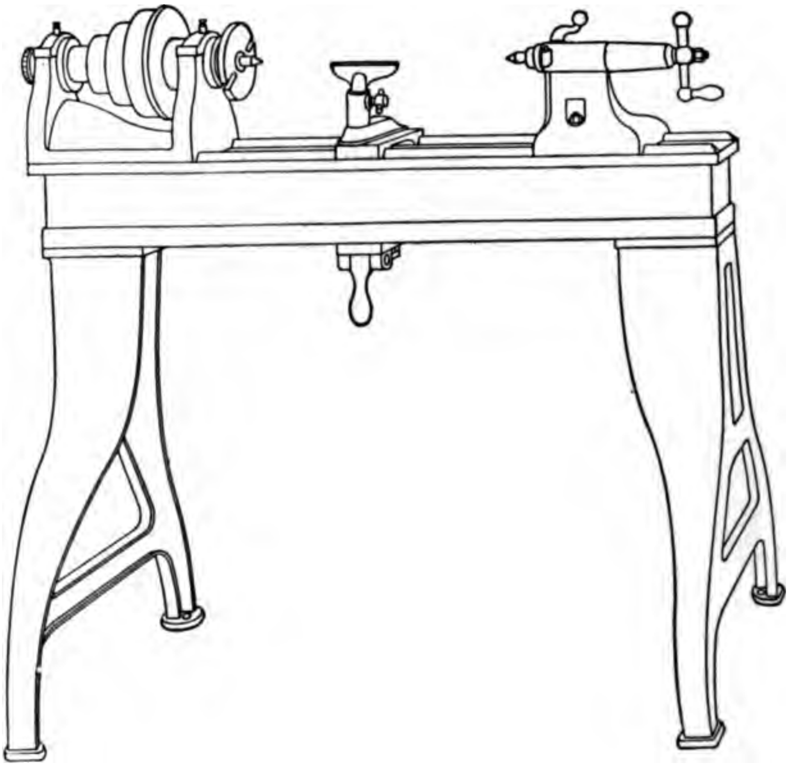
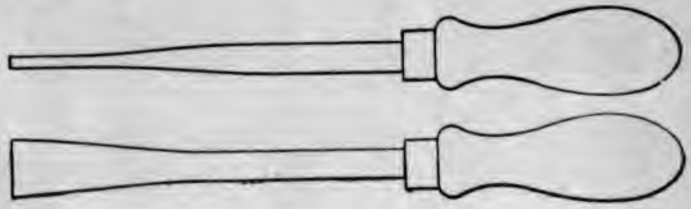


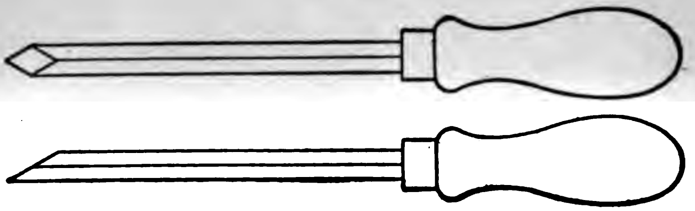
Fig. 83.

steamships or the rings for the heavy ordnance of battleships and fortifications.

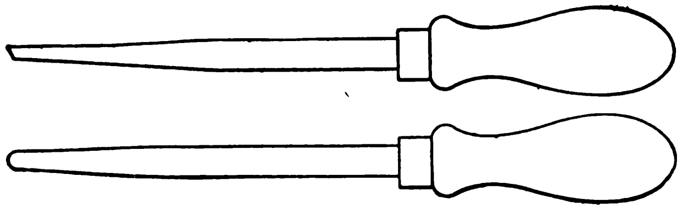
Speed Lathe. The small lathe used in the machine shop for the operations of hand turning, filing, and polishing is called the hand or speed lathe, Fig. 83. This type driven by foot power is in great favor with amateur workmen. While hand turning is avoided as much as possible, it cannot be wholly eliminated, and a brief description of the tools used and the operations performed seems necessary.



Planisher.



Graver.



Round Nose.

Fig. 84.

The tools used on brass and composition cut by a scraping action, and are almost always held at or below the center. The three tools shown in Fig. 84 called the planisher, graver, and round nose, are typical of all the tools necessary for turning brass, etc. The manner of holding these tools in connection with the T-rest is illustrated by the planisher in Fig. 85. Fig. 86 shows another view of the T-rest. Typical hand tools for cutting iron and steel are the diamond point or graver and the round nose, shown in Fig. 87. They are used differently from hand tools for brass, in that the cutting edge is carried above the center, and the metal is removed by cutting instead of scraping. The graver frequently takes the place of the planisher, for it can be used as shown in Fig. 88, either on the outside or on the end of a piece of work. The round nose is used solely for concave surfaces, being held as high on the work as proper cutting will allow; Fig.

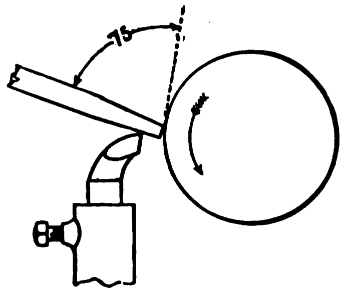


Fig. 85.

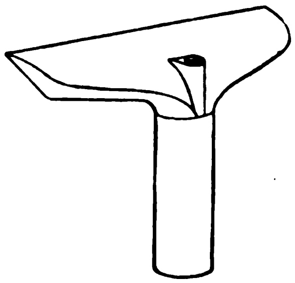


Fig. 86.

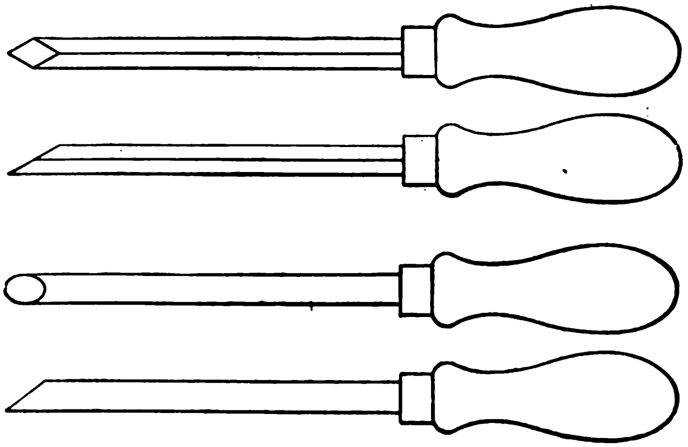


Fig. 87.

89. The graver can be used on brass for a great variety of operations; but its use, except in the hands of an expert workman, is attended with danger of catching in the soft metal and thus breaking the tool or spoiling the work.

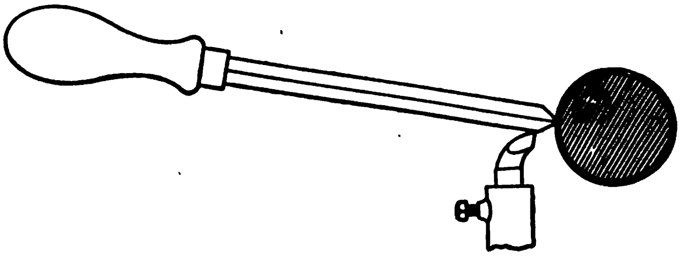


Fig. 88.

To make the hand lathe more rapid and certain in operation, it is frequently provided with a tool holder, called the slide rest, Fig. 90. This holds the tool rigidly and guides it mechanically, so that the work is done more rapidly than with hand tools. Slide rest tools are miniatures of those used on larger lathes, hence a description will not be given at this point.

Engine Lathe. When the slide rest is permanently attached to, and movable along, the bed of the lathe, and motion is automatically imparted to the tool, we have what is termed the engine lathe. This is one of the most common, as well as one of the most important machine tools, and one which can be made to serve for a wide variety of operations. For these reasons, it is entitled to a more extended description than that accorded to less typical forms.

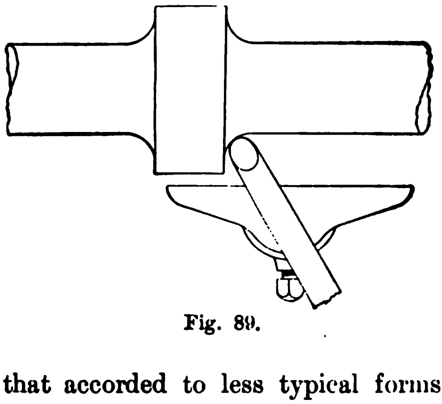


Fig. 89.

An ordinary form of screw cutting engine lathe is shown in Fig. 91, which is a representation of one of usual dimensions. It has a strong cast-iron bed A, carried on four well braced legs, that may be bolted to the floor, though the weight of the machine may be sufficient to hold it in position. On the left-hand end of the bed there is fastened the head stock B, which carries the main running gear of the machine. At each end of the head stock there is a bearing for the spindle. Running loosely on the spindle and between the bearing is the cone pulley C to which the pinion D is attached.

The back gear is designed to reduce the speed of the spindle without changing the belt speed. The mechanism of the back gear is more clearly shown in Fig. 92. The large gear E alone shows in Fig. 91. It is driven by the pinion D which is attached to the cone. The pinion on the same sleeve as the gear E drives the gear at the right of the cone. This gear is keyed to the spindle. When the back gear is not in use it is thrown out of mesh with the gears on the pulley and spindle, by means of the shaft having eccentric bearings upon which it turns; at the same time the cone pulley is fastened to the gear at its right. The spindle then turns with the cone pulley. When the back gear is in use the spindle runs more slowly, with the belt on the same step of the cone, than it does when driven direct.

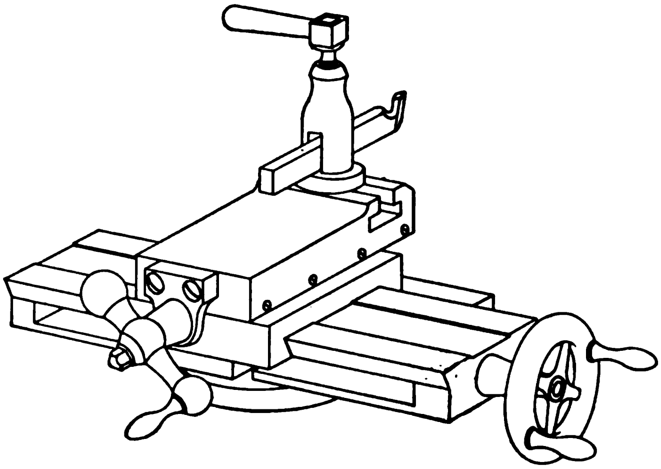


Fig. 90.

The spindle projects through the bearings at each end. At the right it is usually threaded to receive a face plate F. It is

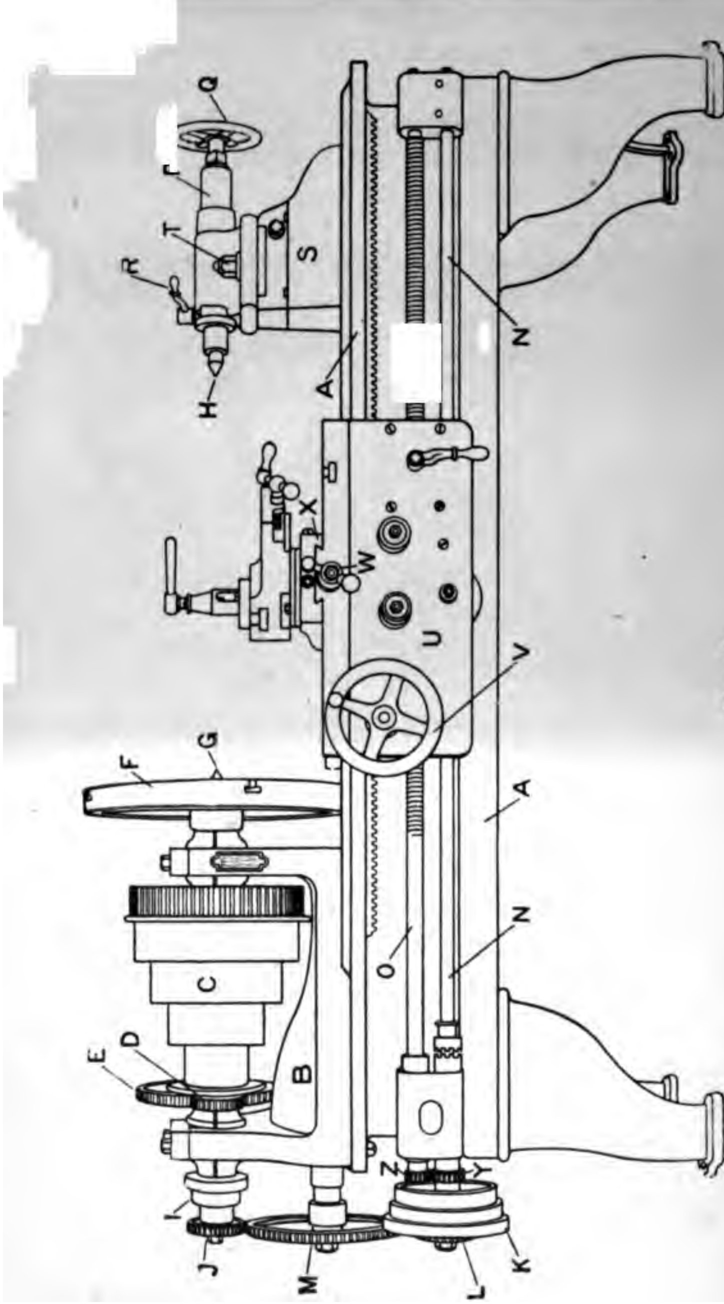


Fig. 91.

also bored out and tapered at the end for a center G. This center is called the *live center* because it turns with the spindle. The *dead center* H is in the tailstock, and hence does not turn. At the left the spindle projects beyond the bearings, and carries a small cone pulley I and a pinion J. The cone pulley serves as the driving pulley for a narrow belt running to the corresponding pulley K on the feed rod N. The pinion serves to drive, through the intermediate gear M, the lead-screw O.

The work is held on the centers G and H, the distance between which is adjusted by moving the tailstock S (sometimes called the tailblock). The latter is held to the bed by a clamp and bolts tightened by the nuts T. To move the tailstock, these nuts are slackened and the stock moved to the proper position. The final adjustment is made by turning the hand wheel Q, which rotates a screw in the case P, which works in a nut in the spindle of the dead center H which is thus moved in and out. When the centers have been properly adjusted and the work is in position, the dead center is clamped by the handle R.

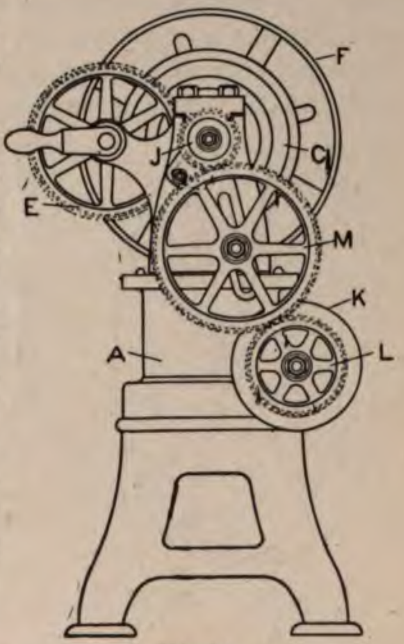


Fig. 92.

When work is to be turned, the tool is properly adjusted, and the carriage U moved along the bed. This movement is accomplished by means of gearing, which is placed behind the apron of the carriage, and driven by the shaft upon which the cone pulley K is keyed. The driving gear meshes with a rack beneath the upper ledge of the bed. Connection between the gearing and the shaft is made by a friction clutch. The carriage may also be moved by hand, by turning the hand wheel V, to which there is keyed a pinion directly meshing in the rack.

The tool is fed to the work and withdrawn from it by turning the cross feed handle W. This drives, by means of the screw and nut, the cross slide X. This arrangement permits any desired transverse or longitudinal position of the tool. The motion of the carriage is usually from right to left when at work. When screws are to be cut, a different feed is used. In ordinary turning there will be a variation in the relations between the rotation of the work and the longitudinal motion of the tool due to the slipping of the belt connecting the cone pulleys I and K, or to the slipping of the friction clutch connecting the shaft K to the driving gear. To cut a screw thread it is necessary that there shall be no relative change in the rotation of the work and the longitudinal motion of the tool. In other words, the tool must travel a given distance for every revolution of the work. To accomplish this, the carriage is driven by the lead-screw O working in a nut set in the carriage. The screw is, in turn, driven by the train of gears J, M, and L. The gear J is keyed to the spindle. The intermediate gear M runs loose on a stud. The gear L is keyed to the feed rod N, which transmits its motion to the lead-screw O by gears Y and Z. By changing the sizes of the gears used on the spindle and the screw, any desired thread may be cut. The size of the intermediate gear M has no effect on the thread being cut. It is used to connect the other two gears, and can be adjusted to any desired position for that purpose.

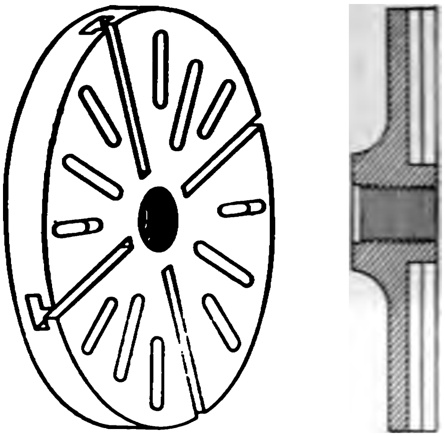


Fig. 83.

In this country the SIZE OF A LATHE is designated by the largest *diameter* it will swing over the guides, and by the length of the bed. The lathe illustrated is known as 24″ × 8′. In England the distan — the guides to the center is the unit of size, ar t distance between centers is considered to be the length of the lathe. Thus a 15-inch lathe in England would be a 30-inch lathe in the United States.

The attachments usually furnished without extra charge are a large face plate of the full swing of the lathe, a steady rest, and a follower rest.

The small face plate is used only for driving the work indirectly through suitable attachments. The large face plate shown in Figs. 91 and 93 is used as a direct support for the work, the T-slots and other openings furnishing opportunities for bolting and clamping the work firmly to the face plate.

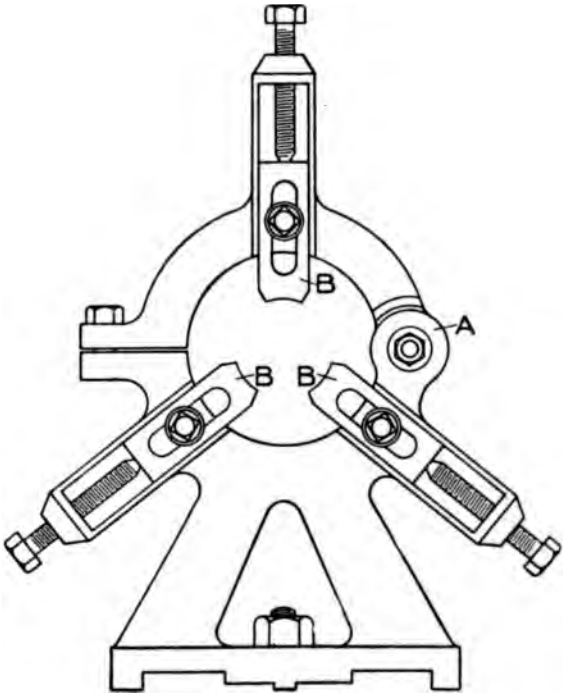


Fig. 94.

The Steady Rest. When work is being done on the end of a shaft so that the tailstock cannot be used, it is necessary to support the shaft in some other way. It is done by means of the steady rest shown in Fig. 94. This rest consists of a frame hinged at A, and fitted with three movable jaws, B B B. The rest is clamped to the lathe bed in the proper place. The jaws B B B are then adjusted to form a bearing for the work, care being taken that the axis of the work is parallel to the ways, or shears. Unless it is parallel, the work will not be turned true; that is, the end will not be square, but will be hollowed or conical, as shown somewhat exaggerated in the accompanying diagram (Fig. 95). The steady rest is also used to support long shafts that are being turned; it prevents such work from sagging at the center and thus being turned out of true.

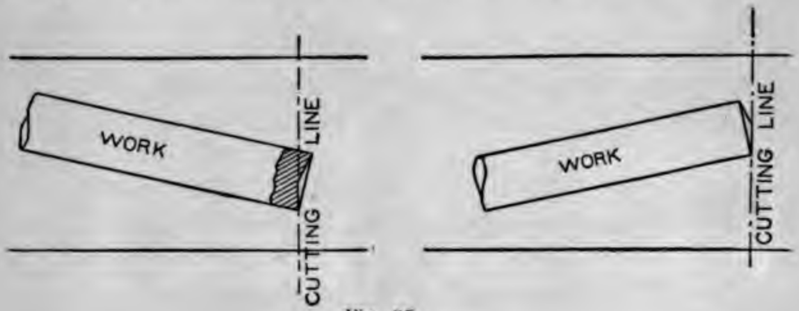


Fig. 95.

After adjusting the steady rest to size, it can be moved along the bed of the lathe without changing the relation to the lathe axis; but care must be taken not to reverse the steady rest in the lathe, as, in most cases, such action would necessitate a readjustment.

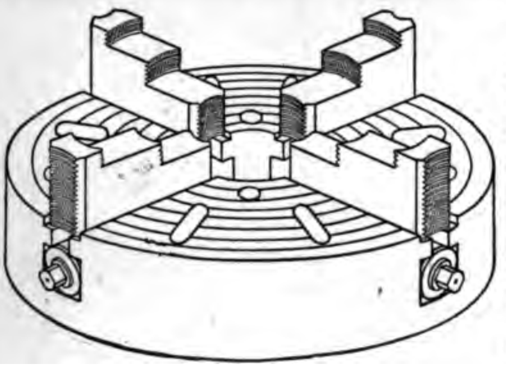


Fig. 97.

The names, back rest and center rest, are synonymous with steady rest, the use of the device often determining the name.

The follower rest serves some of the purposes of the steady rest, but is fastened to the carriage, and moves with it at the point of greatest stress. It may consist of adjustable jaws or a solid ring to slip over the piece being turned. It is especially valuable in turning shafting and other work where the ratio of length to diameter is very great. The follower rest is not very often used in shop practice, except on classes of work just mentioned. The extra attachments desirable for a lathe will now be briefly described.

Chucks. First in importance is the lathe chuck, Fig. 96. It consists of a body which is fastened to a special face plate in such

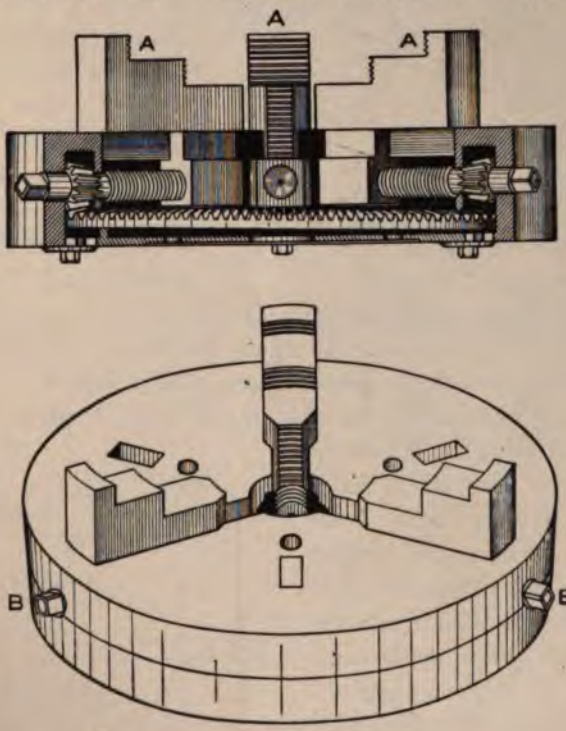


Fig. 96.

a way that it is concentric with the spindle. The three jaws AAA can be moved in and out toward the center by turning the screw-heads BBB. These chucks are universal or independent. In the universal chuck all of the jaws are operated simultaneously. That is, when one of the screw heads B is turned, all of the jaws are moved an equal distance towards or away from the center. This makes it possible to put the work in position quickly if it is pproximately round in its unfinished condition. With the independent chuck, Fig. 97, each jaw is operated separately. Such a chuck is used for holding pieces of irregular shape and those which must be held eccentrically. Frequently the universal and independent chucks are combined in one. Means are then provided for working the jaws separately or together as desired.

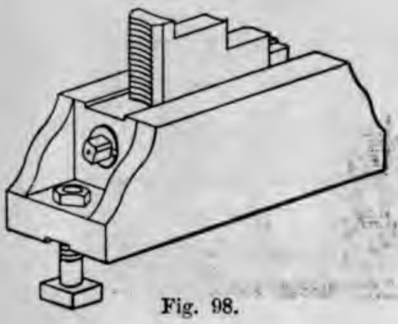


Fig. 98.

In using the universal chuck each screw should be tightened. The method of procedure is to place the work in the chuck, and turn one screw head until all of the jaws are in contact with the piece to be operated upon. Then turn the chuck and tighten each screw head successively until each one is tight enough. Owing to wear and lost motion, it is sometimes necessary to apply the wrench to each one three or four times before the final adjustment is reached.

Lathe chucks are usually made with three or four jaws. Universal chucks generally have three jaws, while independent chucks have four. It follows that a combination chuck is not wholly satisfactory, because with three independent jaws it is very difficult to adjust work accurately, and with four universal jaws it is equally difficult to get every jaw to bear on the work. For certain classes of work, especially valves and pipe fittings, chucks with two jaws are often used

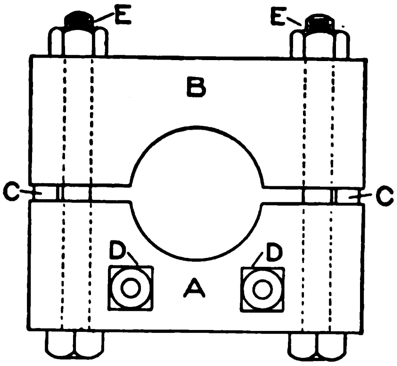


Fig. 99.

The large face plate of a lathe can be made into an independent chuck by attaching what are known as face-plate jaws; Fig. 98. In this case, there may be six, eight, or more jaws.

As these chucks are expensive it sometimes happens that a piece is to be held for which no provision is made. A chuck can then be made of wood. Such a chuck is shown in Fig. 99. Two pieces of wood, A and B, are bolted together by the bolts EE, while separated by the filling pieces CC. The piece is firmly bolted to a face plate by the bolts DD. The lathe is then run at high speed, and the interior bored out exactly the size of the piece that is to be held. The nuts of the bolts EE are slackened and the filling pieces CC removed. The work is then inserted, and by tightening the nuts EE, it is securely clamped between the pieces A and B.

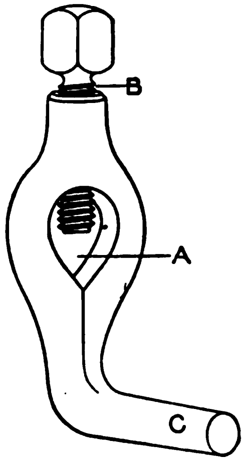


Fig. 100.

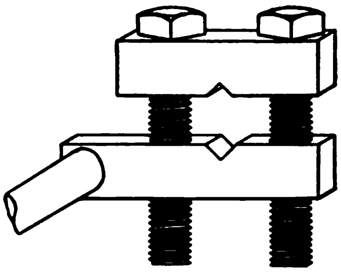


Fig. 101.

Lathe Dogs. As the frictional contact of the work on the live center is not sufficient to turn it, some device must be used to make the work turn with the center. To accomplish this a lathe dog is used. For round work, such as shafting, a dog like that shown in Fig. 100 is often used. The shaft or piece to be turned is placed in the hole A, and held firmly in place by the set screw B. The tail-piece C is put through a hole in the face plate and the work rotates with the live center.

While this type of dog is satisfactory in most cases, the fact that the contact between the dog and the face plate is beyond the end of the piece, introduces a bending strain which is appreciable in slender work. To avoid this, dogs are made with a straight tail, and driven by a stud projecting from the face plate.

For work other than round, a dog such as that shown in Fig. 101 may be used. The work is placed between the jaws, and held in position by the bolts. The holes in the upper jaw are made larger than the screws in order that the angle between the jaws may be varied. The connection between the face plate and dog is made as with Fig. 100.

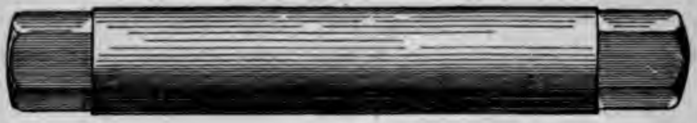


Fig. 102.

Mandrels. Another method of holding work is by the use of a mandrel. This is a piece of steel with a slight taper; the ends are flattened for the lathe dog, as shown in Fig. 102. It frequently happens that a piece with a hole in it is to be turned or finished over its outer surface. In this case a dog cannot be used, and it is troublesome to hold it to a chuck. Such a piece is shown in Fig. 103. This is a stuffing-box gland. If it were to be held by the jaws of a chuck the face A could not be reached at all, and only a portion of the edge B, whereas a dog clamped to it would offer even greater obstruction. The method of using the mandrel is to ream the gland out, so that it can be driven upon

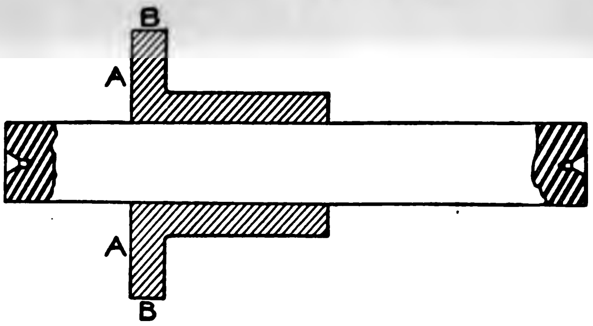
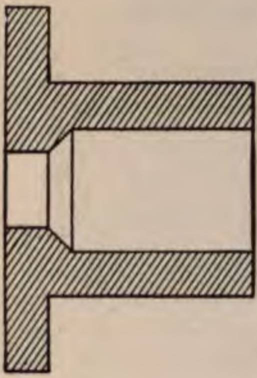


Fig. 103.

the mandrel. When this has been done the frictional resistance between the two will be sufficient to drive the piece. In this manner it can be finished over its whole surface with but one setting in the lathe. All finishing possible may be done while it is in the chuck, leaving, in this case, only the face A and edge B to be finished while on the mandrel.



Should the gland be shaped, as shown in Fig. 104, it would be necessary to make a special mandrel to fit the bore. The cylindrical part of A of the mandrel must be a driving fit, and the part B a loose fit.

Expanding Mandrels. Where a mandrel like that shown in Fig. 102 is frequently used, the constant driving on and off of the work will wear it to a smaller diameter, causing it to become useless. Again, solid mandrels are usually made of standard diameters, varying by sixteenths of an inch. It sometimes happens that a piece to be turned has a hole which will not fit any standard solid mandrel.

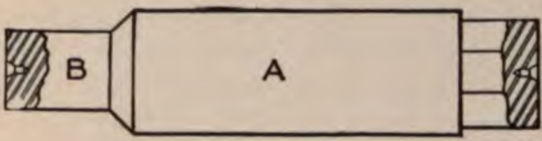


Fig. 104.

To overcome these difficulties an expanding mandrel, shown in Fig. 105, is used. This is really a chuck so arranged that the grips can be forced out against the interior of the hole. When the work has been finished the grips are again drawn in and the piece removed. Another form of expanding mandrel is shown in Fig. 106.

Centering. A piece to be turned is supported on the two centers of the lathe. In order that this may be done, the ends are prepared by drilling a hole in each and countersinking it. This is called centering the work. The countersink should be of exactly the same angle as the lathe center upon which it is to run. The hole should be drilled deep enough so that the point of the lathe center may not strike. The shape of the hole is shown in Fig. 107. The angle of the hole varies from 40° to 90°, but 60° is the generally accepted standard. The effect of using a 60° hole on a 90° center is shown in Fig. 108. The result of such an application is that the bearing will be concentrated on a line AB causing rapid wear of the outer end of the hole, and a cutting of the dead center.

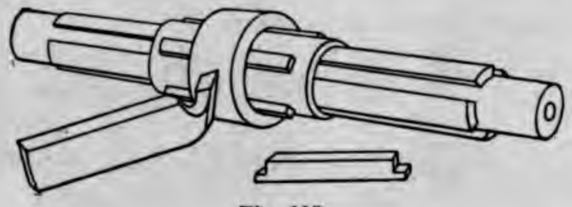


Fig. 105.

The size of center holes varies with the weight of the work and the character of the operation. Heavy work and rough turning require large center holes, while small work and fine turning can be done without countersinking deeply. As bearing surfaces in cast iron must be large to be satisfactory, center holes in cast iron are likely to give trouble by unequal and rapid wear. When turned work in cast iron must be very accurate, it is well to drill a large hole in each end, drive in a plug of wrought iron or mild steel, and form the center holes in the plugs thus driven.

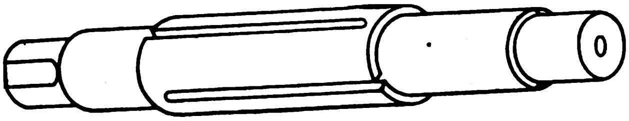
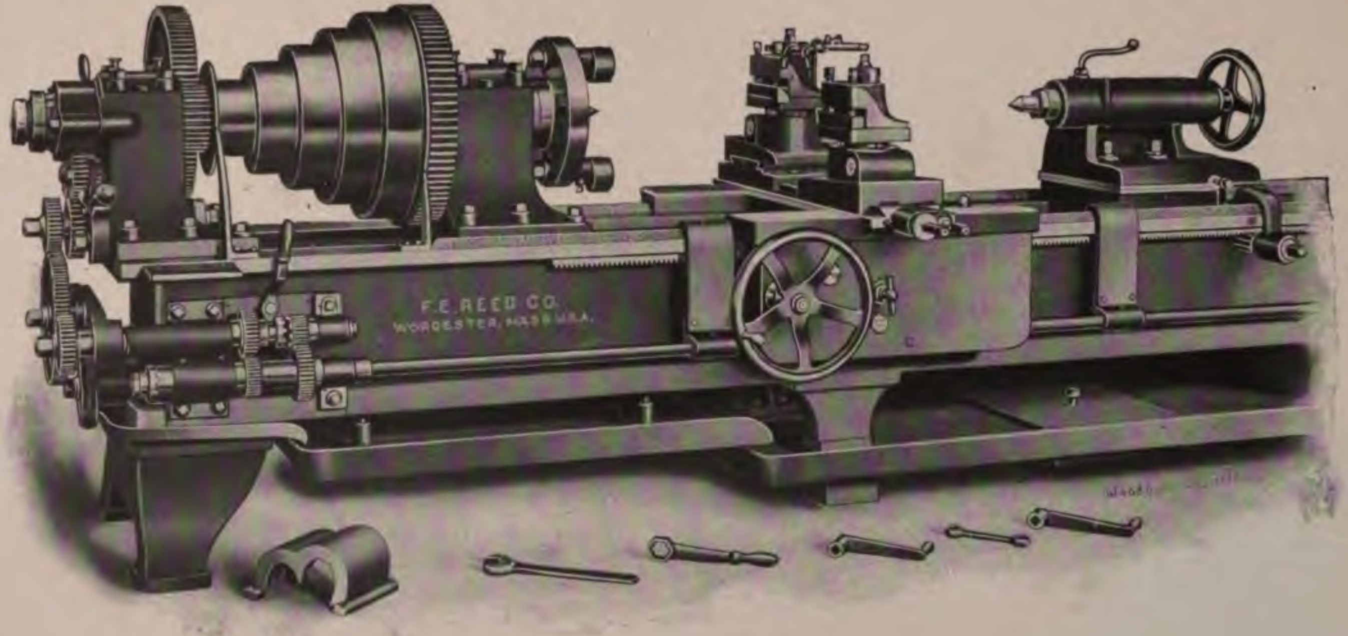


Fig. 106.

When the piece has been put in place, the dead center should be oiled and screwed up into position. It should be tightened so that there is no lost motion and yet allow the work to turn freely.

The turning of shafts and bars is not, however, the only kind of work to be done on a lathe. Pieces are to be turned that are thin, that have holes through the center, and which are so shaped


F. E. REED CO.
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24-INCH SPECIAL LATHE.

F. E. Reed Company.

that they cannot be held upon the centers. In such cases it becomes necessary to hold the work firmly without distortion, as may be done by use of the lathe chuck.

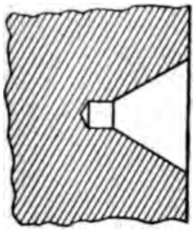


Fig. 107.

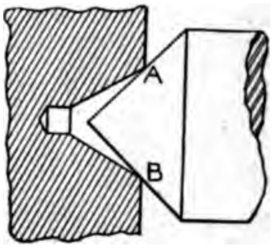


Fig. 108.

Still another method of holding work is that shown in Fig. 109. The piece is clamped to the face plate. When this is done there should be a bearing on the face plate immediately beneath the clamping strap. For example consider Fig. 110. Suppose a disk having four feet on one side is to be faced off on the front.

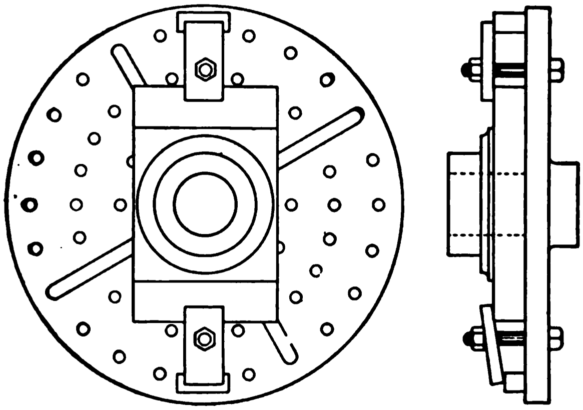


Fig. 109.

The clamps should be placed directly over the feet as in B. If they are placed between the feet at EE the work will be sprung out of shape as shown by the dotted lines in A. Then, when the tool has done its work the shape of the piece, while bolted to the face plate, will be as shown in C. As soon as the pressure of the straps is removed the elasticity of the metal will cause the piece to assume the convex form shown in D, whereas, if the straps had been placed as shown in B, no distortion would have been produced.

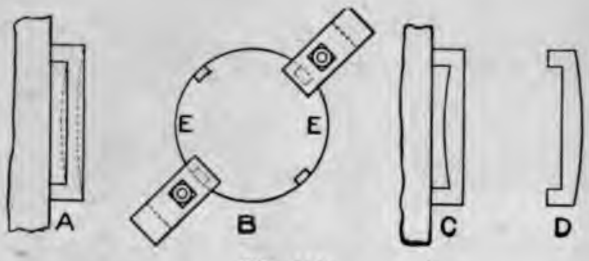


Fig. 110.

An angle iron may be clamped on a face plate, as shown in Fig. 111, presenting a surface parallel to the lathe axis to which work may be attached. The angle irons may of course be at any angle to the face plate, but 90° is the one most commonly used.

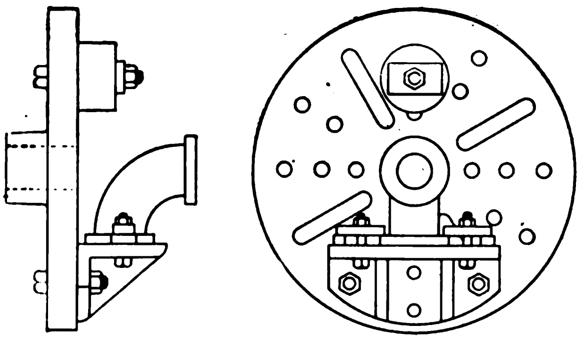


Fig. 111.

When work is held in this manner, it is desirable to counterbalance it, as is also shown in Fig. 111.

Adjusting Pieces to Center. Whenever a piece is to be turned in a lathe it is necessary to adjust it so that its rough outline is approximately concentric with the lathe centers. This is done by bolting it lightly to the face plate and running the lathe. While running, a piece of chalk is held so that the projecting portions will strike it. This marks the piece, and indicates the part that is *farthest* from the center. The lathe is then stopped and the piece shifted, *moving the chalk mark towards the lathe center.* This is repeated until the chalk makes a continuous mark around the whole circumference. The piece may then be considered to be centered.

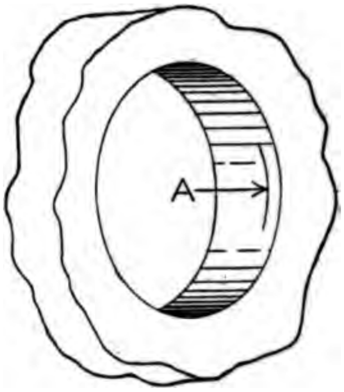


Fig. 112.

Suppose it is necessary to center a piece having a hole that must run true. In this case the inside of the hole must be used as a guide. Let Fig. 112 represent the hole with the thin shell, and A a chalk mark made as described for centering by the outside. In this work the *chalk mark must be moved away from the center.* A lathe tool may be used as shown in Fig. 113 to center a piece that is to be bored.

Where a piece has already been turned, greater accuracy is demanded, and a surface gage may be used to advantage. Set the gage on the bed or carriage of the lathe, and place one of the points in contact with the work. Rotate the work as before, and note where the point touches the surface. This point is to be treated in the same way as the chalk mark explained in a preceding paragraph.

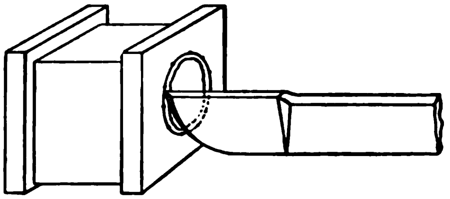


Fig. 113.

A still more accurate method of centering a piece of turned work on a face plate is to use some form of graduated indicator, such as the Starrett indicator, Fig. 114. This is held in the tool post, and the contact point brought against the work until the indicating arm is at zero. If the work is now slowly rotated by licator will show just where the work is out of true, raduated in thousandths of an inch, will also show By careful adjustment, the piece may be centered to degree of accuracy required.

Instead of locating a cylindrical surface concentric with the of the lathe, it often happens that a point is to be located in x For this purpose, the center indicator, Fig. 115, is free end of the short arm is placed in the point to be ually a prick punch mark), the fulcrum being held in

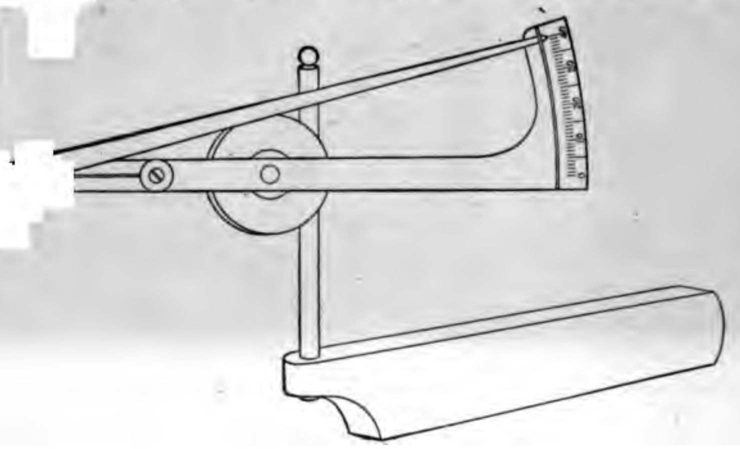


Fig. 114.

the tool post; when the work is rotated, the free end of the long arm not only shows the error, but magnifies it in proportion of the length of the short arm to the length of the long arm. By using a comparatively long arm, the point can be very closely centered.

Centering Finished Work. After making the center punch mark in the end of the piece, it is drilled and countersunk. This must be done very accurately, but frequently the drilled hole or the countersink will not be in the exact center. See Fig. 116. This may be caused by uneven grinding of the drill, eccentric motion of the drill point (due to the inaccurate running of the spindle), or the distortion of the metal by the center punch. If the countersink is not exactly in the center, it must be drawn back to the center. This is generally done by the small round-nosed chisel and a hammer. The method of doing this work is as follows: After making the center punch mark, the hole is drilled and then countersunk slightly. The work should now be stopped; and if the circumference of the conical hole is not concentric with the circumference of the piece a groove should be cut down the side farthest from the outer circumference, as shown in Fig. 117. The depth of the groove, which should be near the center, depends upon the amount of eccentricity. The countersink is again started and the groove drilled out. If the circle is not yet concentric, the process is repeated.

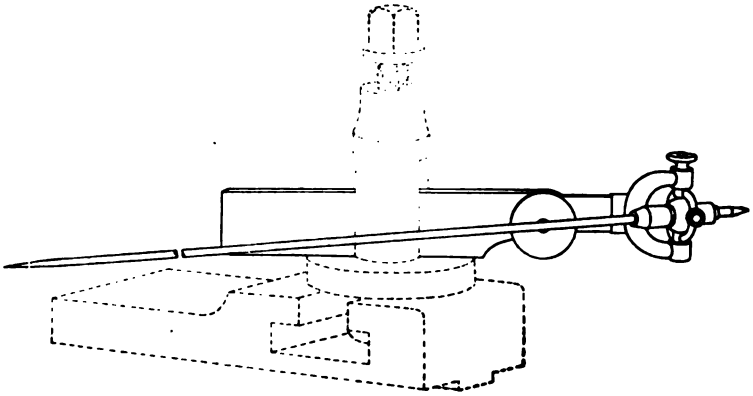


Fig. 115.

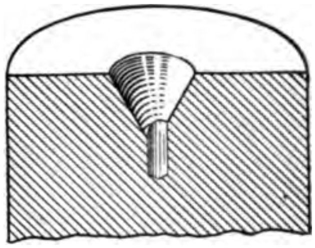


Fig. 116.

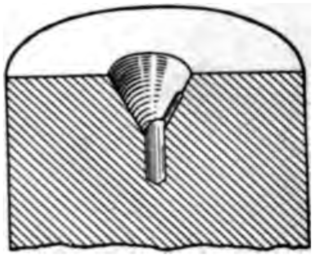


Fig. 117.

Lathe Tools. The cutting tools used in lathes are of a great variety of shapes. These shapes are adapted to the work that is to be done, and to the kind of finish that is to be left upon the are two fundamental requirements that all tools *The cutting edge alone must touch the metal; the edge keen.* A typical form of tool is shown in Fig. 118. The edge of the tool at A is in contact with the work. The bottom line A B runs back from the metal and does not touch it. The top face A C slopes down and back. The line A D is a tangent at the cutting point, and the line A E is radial at the same point.

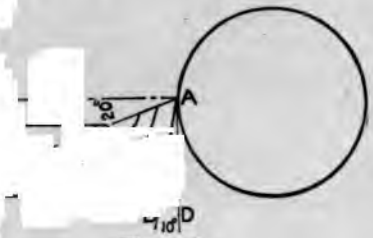


Fig. 118.

he angle D A E is always a right angle or 90°. The B is called the angle of *clearance*, and should be lathe tools, not over 10°. The angle C A E is called of *rake*, and should be as great as circumstances will per- out 20° on lathe tools for wrought iron and steel, leaving r the *solid* or *cutting* angle, which is the same angle as is used for a cold chisel.

Clearance prevents the tool from rubbing on the work, while rake adds to the keenness of the cutting edge, and gives freedom to the removal of the chips. A tool should have sufficient strength at the point to do the work required.

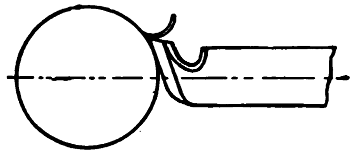


Fig. 119.

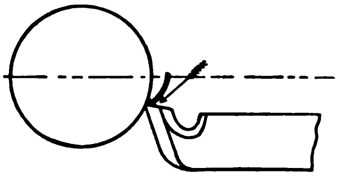


Fig. 120.

The tool should be set so that the cutting edge will be very nearly at a horizontal line, passing through the axis of the work. Many machinists set the cutting edge a little above the horizontal line. When so set the stress tends to force the tool down along the line of its greatest strength. The tool may, however, be set too high. If this is done, as in Fig. 119, the angle of clearance will disappear, and the curve of the work will rub against the bottom of the tool. This will tend to force it out; it will heat the steel and produce a rough surface on the metal being turned. If, on the other hand, the tool is set too low, as in Fig. 120, the cutting edge does not stand in line with the motion of the work at the point of contact. The result will be that the metal will be scraped rather than cut, as there is no rake, and the pressure upon the tool will be in the line of its lowest power of resistance, as indicated by the arrow. Such a position might cause the point of the tool to break off. It will also cause the tool to tremble or chatter as it removes the chips, leaving a rough and wavy surface on the metal.

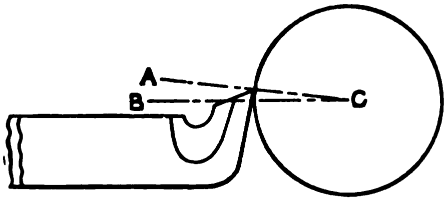


Fig. 121.

As stated above, many machinists prefer to set the cutting edge a little above the center; if this is done, the rotation of the work has a tendency to depress the point of the tool a little, bringing it, while cutting, nearly to the center. The amount the tool is set above the center is slight, and of course depends upon the character of the work. The angle A C B, Fig. 121, should be only about 5 or 6 degrees.

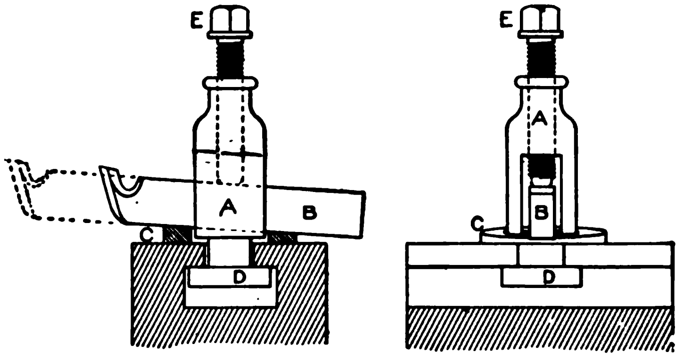


Fig. 122.

ool usually held to the carriage by means of a tool post, I 122. The post consists of a piece with a slotted ugh the center for the tool B. A ring C slips over it ts upon the body of the carriage. This ring may be beveled as shown, to provide vertical adjustment for the point of the tool. The post has a collar D at its lower end that goes loosely into a slot in the carriage. At the top there is a set screw E. When the tool has been properly adjusted by turning the ring C to give it the correct elevation, the set screw is wn upon the top of the tool. This raises the tool bearing on the under e slot, and clamps hole carriage firmly in position.

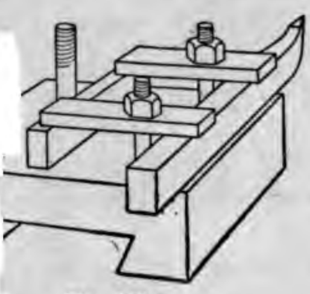


Fig. 123.

In setting the tool, it should be done with the cutting edge as far back towards the supporting ring as possible. If it has too much overhang, as shown by the dotted lines of Fig. 122, it will spring under the pressure of the work and chatter.

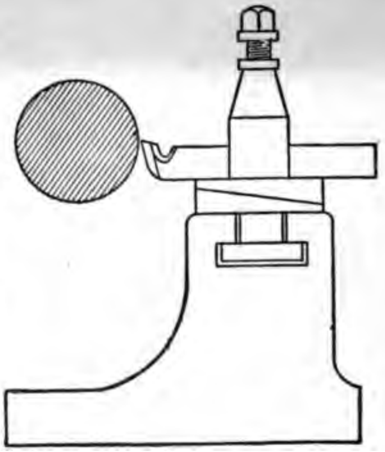


Fig. 124.

While this form of tool post is used more than any other, there are certain objections to it. In the first place, changing the height of the tool point also changes the angles of rake and clearance. These are supposed to be correct when the base of the tool is horizontal. Any change from this position will alter these angles materially. Again, this post is not rigid enough for heavy work. On lathes of over thirty inches swing, the style of tool-holder shown in Fig. 123 is often employed.

English manufacturers use it almost exclusively on all sizes. There is no provision for raising and lowering the point of the tool; and while this is not of serious importance on large lathes, 30-inch and over, it becomes a matter of moment when turning such work as is usually handled in lathes of 14-inch and 16-inch swing.

The form shown in Fig. 124 has two beveled rings to adjust the height of the tool.

The Lipe tool post, shown in Fig. 125, combines the good points of all the other forms; the tool can be held by one or two screws as the character of the work may require, and the tool may be adjusted vertically and horizontally after being clamped down. The construction and operation of this tool post are so evident from the illustration, that further description will not be given.

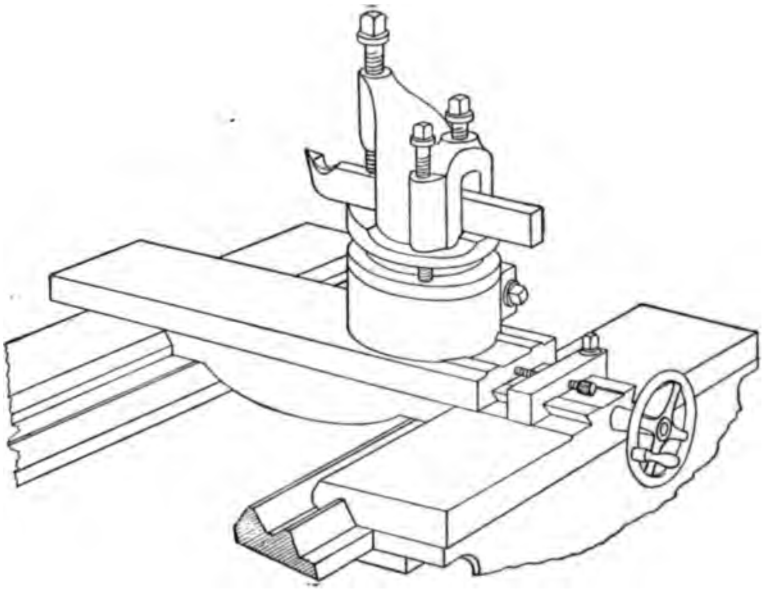


Fig. 125.

An entirely different method of adjusting the tool point is by means of what is called the elevating or rise-and-fall rest shown in Fig. 126. In this type there is a T-shaped casting carried on the upper part of the carriage, supported by trunnion screws at and by an adjusting screw at the rear. With this is st as shown in Fig. 122 with a plain ring. The rest is used quite extensively on small lathes, but the ce of adjustment is gained by a loss in rigidity. The light, and the elevating portion, being supported at separated points, lacks stiffness. As the effective carriage is limited by the height of the cross rail arried above it, they are made light — too light in

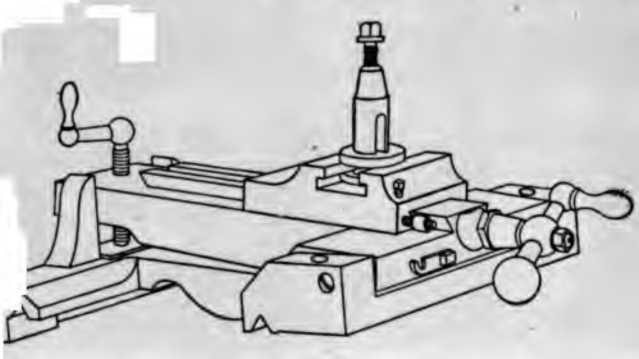


Fig. 126.

Turning Tools. The side or facing tool, Fig. 127, is the most common form of lathe tool. It is used for squaring up the ends of shafts, facing shoulders, and similar work. While the ordinary forms will not remove a large amount of metal, they can,

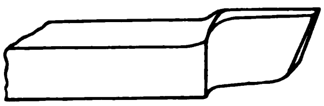


Fig. 127.

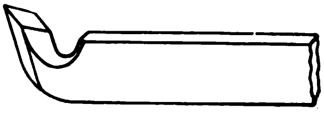


Fig. 128.

when made thick and heavy, be used for roughing cuts on the surface of cylindrical work. The common form is made slender in order to work between the dead center and the work in squaring up ends.

A common form of tool for turning wrought iron and steel is the diamond point shown in Fig. 128. The name is derived from the shape of the top face. This tool has both front and side rake which allows a keen edge without reducing the strength. It is used for finishing only when the point is ground slightly rounding and a fine feed is used. In finishing, but little metal should be removed. The *Feed* of a tool is the amount of longitudinal advance at each revolution of the work. For roughing out cast iron, a strong and rapid working tool is a round nose with considerable side rake. For finishing wrought iron and steel, a modification of the diamond point, as shown in Fig. 129, is often used. For cast iron, a square-nosed tool, Fig. 130, should be used. It must be carefully ground and accurately set, otherwise it is very likely to gouge into the softer parts of the metal. When finishing wrought iron and steel, the tool should be liberally supplied with oil or soda water. Cast iron must always be worked dry, both in roughing and finishing.

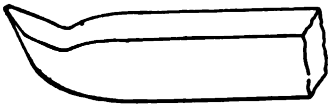


Fig. 129.

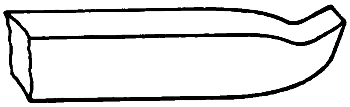


Fig. 130.

The cutting-off or parting tool is illustrated in Fig. 131. The blade is quite narrow; as narrow, in fact, as the character of the work will allow. This is necessary in order that the stock may not be wasted. As the blade must be narrower at the shank and at the bottom than it is at the cutting edge, it follows that the tool is weak. It must be set horizontally so that, as the tool is fed to the work, the cutting edge only will touch the metal. It must also be set so that the cutting edge will pass through the axis of the work as it is fed to the center. If set too high, it will cease to cut before the center of the work is reached, while if too low, the tool has a poor scraping action, and will leave a portion of the work uncut. On work held between centers, one should not

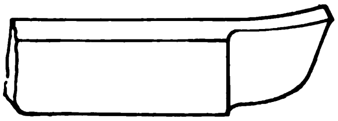


Fig. 131.

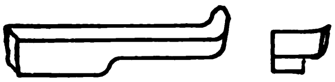


Fig. 132.

attempt to cut to the center of the piece, as the work will surely ride up onto the tool.

Boring Tools. When a hole is to be bored in a lathe, tools of a different shape from those used in turning must be used. The general form of the tool is shown in Fig. 132. The length of the shank at A depends on the depth of the hole to be bored, for it must be long enough to reach from the tool post to the bottom of the hole. This overhang makes the tool more likely to spring, and necessitates a much lighter cut than can be taken when removing the same amount of metal by outside turning tools. The result of this lighter cut is seen in the increase of time required to remove a given amount of stock. The shape of the cutting edge is practically the same as that of the tools for turning, except that the boring tool must have more clearance to avoid striking the work. Therefore, with the same solid angle, the tool will have less rake. The reason for this will be seen by comparing Figs. 118 and 133. In Fig. 118 it will be seen that the surface of the work is outside a tangent at the cutting point, and can never interfere with the bottom of the tool. In Fig. 133 the work surface is inside the tangent; and, unless the tool has a large amount of clearance, it will cause trouble by striking the concave surface.

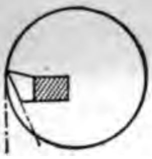


Fig. 133.

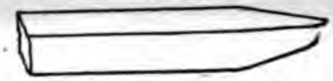
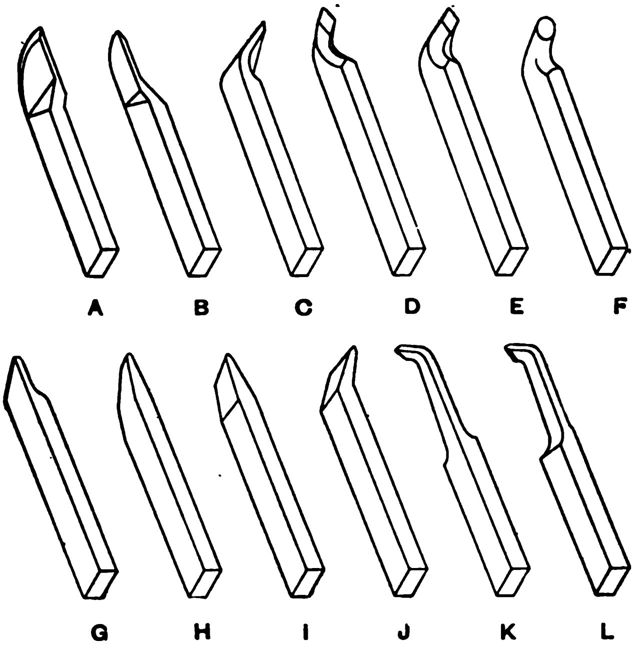


Fig. 134.

Tools for brass differ from those used on steel and iron in that they have no rake. A tool suited for brass is shown in Fig. 134. Brass is a very brittle metal, and the chips break off as soon as started from the main body. When turning wrought iron and steel, on the other hand, the metal does not break, but forms long spiral chips if the tool is in good condition. If a tool with rake is used in turning brass, the work will not only be rough in appearance, but there is great danger of the tool gouging into the stock and spoiling the work or tool, possibly both. The finishing tools for brass may be square or round nosed, without rake; in fact, a small amount of negative rake will produce a much better surface. When the brass contains a large percentage of copper, some rake may be required owing to the ductility and toughness of the metal.

Fig. 135 shows common forms of lathe tools.

The shape of the tool has a very important influence on the amount of work it can be made to do. As has already been explained, these shapes vary with the different metals that are being worked, and also with the class of work performed. It is highly important that the cutting angles be correctly formed. While hand grinding on the emery wheel and grindstone is fairly satisfactory, the best results can only be attained by the use of a regular tool-grinding machine, shown in Fig. 136. In addition,



A	Left-hand Side.	**E**	Left-hand Diamond Point.	**I**	Threading.
B	Right-hand Side.	**F**	Round Nose.	**J**	Bent Threading.
C	Right-hand Bent.	**G**	Cutting off.	**K**	Boring.
D	Right-hand Diamond Point.	**H**	Roughing.	**L**	Inside Threading.

Fig. 135.

tools for fine finishing should be carefully whetted on a fine oil stone.

The cutting speed is an important matter. This varies with the shape of the tool, the quality of the metal being worked, and the strength of the lathe. The amount of metal removed in a given time is, therefore, equally variable. It is impossible to make a correct estimate of the time that a given piece of work will require unless all of the above elements are known. For approximate estimates, the speeds of cutting tools may be taken to range about as follows:

In cast iron,	from 30 to 40 feet per minute.
In wrought iron,	from 25 to 30 feet per minute.
In steel,	from 15 to 25 feet per minute.
In brass,	from 60 to 100 feet per minute.

Suppose a wrought shaft 6 feet long and 4 inches in diameter is to be turned. Let the lathe be capable of carrying a feed of $\frac{1}{32}$ inch per revolution. The shaft has a circumference of $4 \times 3.1416 = 12.5664$ inches. To give the tool a cutting speed of 25 feet per minute, the shaft must make $\frac{25 \times 12}{12.5664} = 24$ (about) revolutions, giving a feed of $\frac{1}{32} \times 24 = \frac{3}{4}$ inch in that interval of time. At $\frac{3}{4}$ inch per minute, it will take $(6 \times 12) \div \frac{3}{4} = 96$ minutes to take a cut the whole length of the shaft. The amount of feed is really the governing element. This may be as much as $\frac{3}{16}$ inch per revolution, and, for finishing cuts, may not be more than $\frac{1}{100}$ inch. The depth of the cut also influences the time required to finish a given piece. This may vary from $\frac{1}{100}$ to $\frac{1}{2}$ inch. All depends on the shape of the tool and the strength of the lathe.

The cutting speeds given above are what may be used with the best grades of tool steel, such as Jessop's, but by using air-hardening or tungsten steels, the speed of cutting may be very much increased over the values given above. These high-speed steels are rapidly coming into favor, more especially for heavy roughing cuts. Not only are the cutting speeds increased, but the chip is made heavier both in depth and feed up to the point where the lathe refuses to carry the load. The ability of this quality of steel to stand high temperatures without injury is the feature which enables it to do work at this rate.

For cooling the tool while performing heavy duty, a solution of sal soda is preferable to water, as it prevents rusting of the work and machinery. The lubricant does not assist in the severing of the metal; even with a most liberal supply, it is doubtful if any ever reaches the point of the tool. Its office is simply to keep the tool cool. If a tool becomes overheated, the edge begins to turn over and it becomes dull.

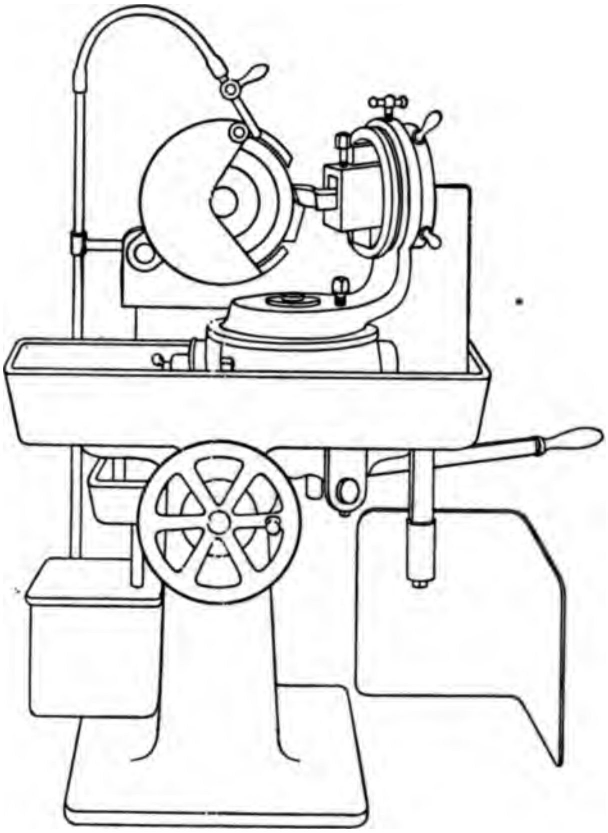


Fig. 136.

Referring to Fig. 120, it will be seen that the chip, as it is being removed, presses down on the top face of the tool. This pressure increases with the depth of cut and the feed. The friction would soon cause a high temperature in the tool if it were not relieved by the lubricant. The lubricant cools the tool by absorbing a portion of the heat, and lessens the amount of heat developed by reducing the friction between the tool and the chip. Clean, pure water is the only lubricant which can be used on cast iron, but the rapid rusting which follows its use makes it undesirable. Brass is also usually turned dry. Prime quality lard oil is sometimes used for cooling the tool; but the greater cost prevents its extended use, unless some means are provided to collect, separate, and filter it.

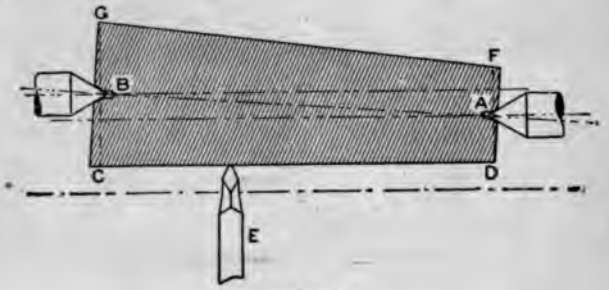
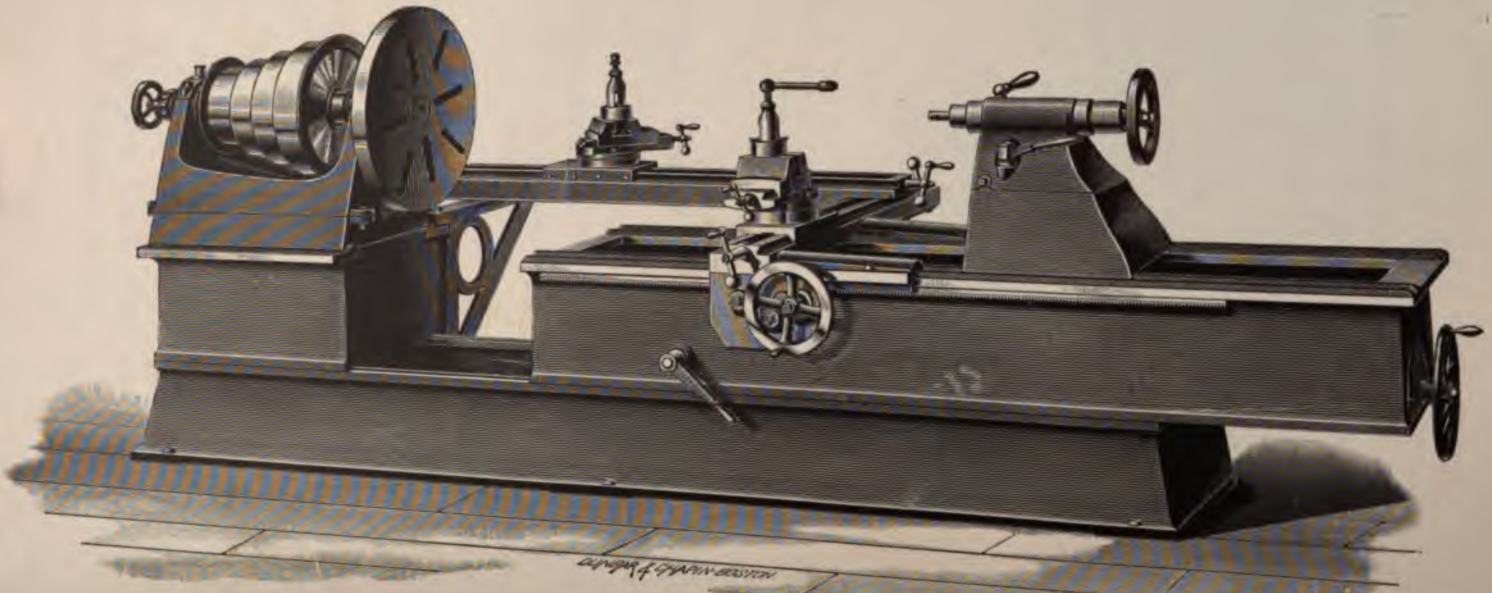


Fig. 137.

Turning. The first operation usually performed on a piece of work when placed in the lathe is facing or squaring up the ends. This must be done to get a uniform bearing for the centers. The finishing of all surfaces at or nearly at right angles to the axis of the work is classed as facing, and the side tool (Fig. 127) is usually employed. For roughing cuts the cutting face of the tool is placed at a slight angle to the work surface in order to remove the metal quickly; but for finishing cuts it is placed nearly flat against the work, so that a light thin chip may be taken.

Turning the cylindrical portions of the work is next done by the use of the diamond point or similar tool. Roughing cuts are taken to within about $\frac{1}{64}$ inch of the finished size, and a fine finishing cut reduces the work to the exact diameter. For roughing cuts, common calipers should be employed, while for finishing cuts, the micrometer caliper is most suitable. All measurements must be taken with the lathe at rest, as motion of the work renders close calipering impossible.



GAP LATHE.
Fay & Scott.

Turning a Taper. It frequently happens that a piece must be turned tapering; that is, one end is to have a greater diameter than the other. There are three ways of accomplishing this result: setting the dead center over, the use of the compound rest, and the use of the taper attachment. Setting the dead center over is the most common method. Provision is generally made for moving the dead center laterally towards the front or rear of the bed according to the taper required. With the dead center set over, the tool will be at unequal distances from the live and dead centers, because its movement is parallel to the axis of the lathe. This is shown in Fig. 137. The piece to be turned is placed upon the centers A and B, and the dead center is moved from the axis a distance equal to the difference between the radii A D and B C. This leaves the side D C parallel to the center line of the lathe; hence the tool will be fed along this line. The objection to doing work by this method is that the lathe centers do not have full bearings at the ends of the work, and the center holes are likely to wear out of their true positions.

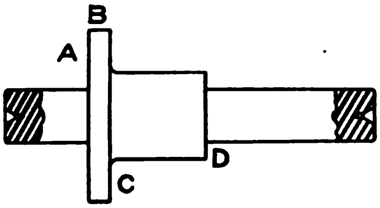


Fig. 138.

If the taper is to be turned on a piece held by a mandrel, or if the taper is to extend but a part of the total length of the work, the amount of set-over for the dead center must be calculated in the same manner as though the taper were to extend the whole length of the mandrel or work. In other words, the amount of set-over for the dead center is determined by the distance between the centers and the rate of taper.

For example: Suppose the mandrel in Fig. 138 to be 16 inches long, and the piece of work C D which is to be turned tapering, is 4 inches long; suppose also, that the diameter at D is to be $\frac{1}{4}$ inch smaller than at C. Then for one inch of length, the difference in diameters would be one-fourth of $\frac{1}{4}$ inch, or $\frac{1}{16}$ inch, and for a length of 16 inches it would be sixteen times $\frac{1}{16}$ inch, or 1 inch. Since the set-over is equal to the difference of the radii, the set-over for the 16 inches would be one-half of 1 inch, or $\frac{1}{2}$ inch.

This, then, would be the set-over for the work under consideration, and for any piece to be tapered at the rate of ¼ inch in 4 inches when held on a 16-inch mandrel.

EXAMPLES FOR PRACTICE.

1. A tapered bushing 3 inches long and of 4 and 4½ inches outside diameters is driven on a 12-inch mandrel for turning. How much must the dead center be set out of line in order to do the work? Ans. 1 inch.

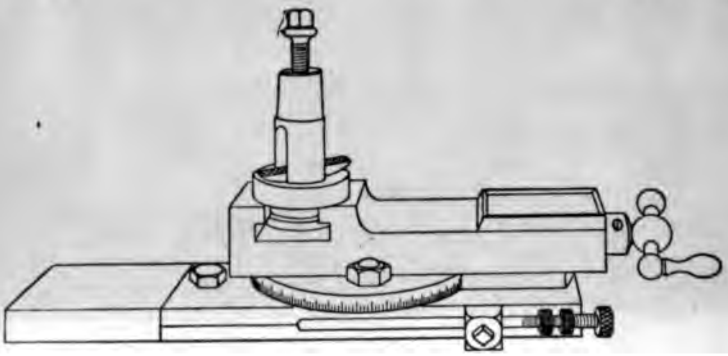


Fig. 139.

2. A connecting rod 6 feet long is to be turned tapering from the center to the neck back of the stub-ends. This distance is 26 inches. The diameter at the center is to be 3 inches, and at the neck 2½ inches. How much offset must be given to the dead center? Ans. .692+inches.

3. A shaft had a taper 2 feet long turned on one end. The large end of the taper was 4 inches in diameter, and the small end was 3 inches in diameter. The dead center was set over 1 inch. How long was the shaft? Ans. 4 feet.

The machinist generally sets over the dead center as accurately as possible and takes a roughing cut. The taper is then tested by a careful comparison of the diameters or by trying it in a tapered hole of the proper angle, and the center set more accurately. Setting over the dead center does not give accurate results, on account of the fact that the centers do not have a true bearing at the ends of the work. The shorter the work, compared with the amount of set-over, the greater the inaccuracy.

In turning a taper with the compound rest, the work may be held in a chuck, on the faceplate, or between the centers. The compound rest, Fig. 139, is then set at such an angle that the direction of the motion of the tool will coincide with the required taper. Several methods are employed for this adjustment of the rest. The tool is then fed to the work by means of the feed handle attached to the compound rest.

The taper attachment, Fig. 140, is in the form of a guide which is bolted to the back of the lathe. It can be set at any desired angle with the axis of the lathe, the limit usually being a taper of about three inches per foot. The guide is graduated so that calculations based on the length of the work are unnecessary. A slide moving with the guide is attached to the cross-feed of the carriage. The cross-feed is loosened, and, while the carriage is moved by the feeding mechanism, the tool is moved in or out according to the direction of the taper.

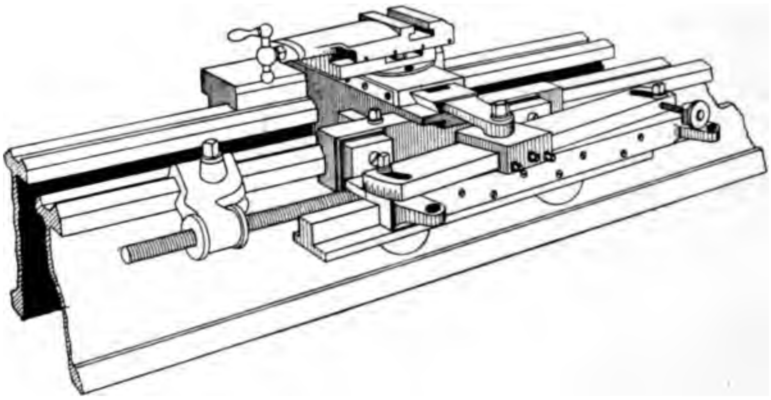


Fig. 140.

One of the most important points to be observed in turning tapers is to have the cutting point of the tool exactly level with the centers. If this is not done, the work will not be truly conical, and, furthermore, the rate of taper will vary with each succeeding cut.

In case an internal and an external taper are to be turned so as to form a fit, the internal taper should, if the character of the work will permit, be made first. After this has been done, the external taper should be turned and tested several times during the process. The external taper is first turned as accurately as possible, taking care that the piece be made a trifle too large. Draw a chalk line on the external taper, from one end to the other, press the tapers together, and give one of them a slight twist. On separating the tapers, the rubbing of the chalk will show where the work was in contact, and, by resetting the lathe and repeating the process, a very accurate fit can be obtained.

Shafting is usually turned $\frac{1}{16}$ inch less than the nominal diameter. For instance, instead of a shaft 2 inches in diameter, one of $1\frac{15}{16}$ inches in diameter is used. The reason is that iron of a nominal diameter of 2 inches, usually $\frac{1}{32}$ inch over size, can be used. Before turning a length of shafting, the rough bar should be carefully straightened. After the center holes have been drilled and the piece placed in the lathe, the work can be turned and the eccentric portions marked with chalk. When this has been done, the bar should be removed from the lathe and sprung back into true alignment. It is well to take two cuts for finishing shafting, one for the roughing cut and one very fine finishing cut. The tool for the latter part of the work should be kept flooded in oil, or a solution of sal soda. If the work is light, a tool-holder, carrying both the roughing and the finishing tools, should be used. This makes it possible to do the work in what practically amounts to the time of one cut.

As a length of shafting is likely to spring under the pressure of the tool, some method of preventing such action must be employed. A steady rest can be used. It is, however, inconvenient and must be frequently moved or it will stand too far, at times, from the tools. Furthermore, as the rough bar will neither be truly round nor concentric with the centers, it is necessary to turn "spots" for the center rest. This operation takes considerable time, owing to the fact that very light cuts must be taken in order to avoid springing the bar. The best method is to have a ring attached to the tool-holder; the internal diameter of this ring is that of the finished shaft. It is slipped over the tail-stock cen-

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ter and follows the finishing tool. It must, of course, be rigidly fastened to the tool-holder. In this way the shaft is supported close to the tools; the ring also serves as a guage to measure the diameter of the shaft. If, for any reason, the tools turn to a larger diameter than the inside of the ring, notice is immediately served upon the workmen to that effect by the binding in the ring.

Eccentric Turning. Up to this point, the work described for the lathe has been of the kind in which the turning is done on work concentric with the lathe centers. There are other classes of work that are offset and for which special provisions must be made. Of course the surface being turned must always be concentric with the spindle.

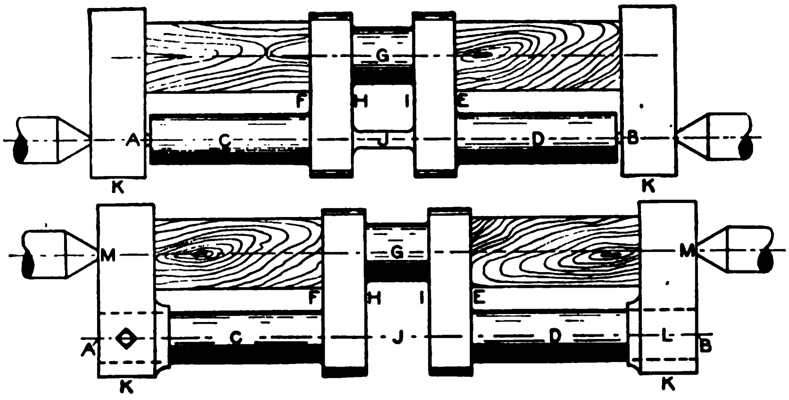


Fig. 141.

The turning of crank shafts presents conditions where there are two cylindrical portions, each parallel to and concentric with the lathe axis while being turned, but eccentric with regard to each other. In Fig. 141 such a shaft is shown. This may be either a casting or a forging. If cast, it is common to have a small web, shown at J, in the original casting to take the thrust of the centers while turning the shaft portions C and D. After centering the work at A and B, the shaft is placed in the lathe, and the ends A and B squared up, and surfaces C and D roughed out. If a forging is being worked, it will be neccessary to insert a wooden block at the point J. Two lugs or ears K are provided to fit tightly on the rough turned shaft, the distance from the center of L to the center M being equal to one-half the throw of the crank. These lugs are attached to the ends of the shaft, so that a line joining the centers M will pass through the axis of the crank pin G. Blocks are now placed between the lugs and the crank pin, the web or block at J removed, and the pin turned on the new centers MM. The crank pin G is roughed and finished, and the shoulders H and I faced, at this time. Removing the lugs and blocks, the surfaces C and D are finished and the shoulders E and F faced on the centers A and B. If the shaft is of any considerable weight, it should be counter-balanced by attaching weights to the faceplate. The reason for not finishing the shaft at the first operation, is that removing the scale from a casting or the outer skin from a forging releases internal stresses which are likely to change the shape of the piece. As a general rule, a piece of work should be completely roughed out, if possible, before any finishing cuts are taken. The change in shape, due to the removal of the outer portion of the stock, does not all take place immediately; and, if very accurate results are desired, it is good practice to allow the roughed work to stand some time before finishing.

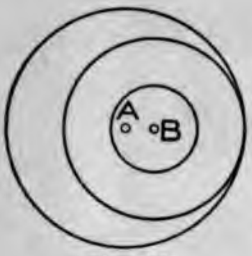


Fig. 142.

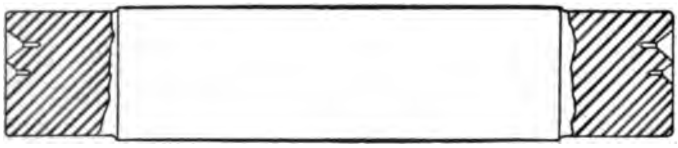


Fig. 143.

Turning an Eccentric. As far as its use in mechanism is concerned, an eccentric is the equivalent of a small crank, but it requires very different treatment in the lathe. In the first place, it is not usually made solid with the shaft, but is a comparatively thin casting or forging which is fastened to the shaft by set screws or keys. The general shape is shown in Fig. 142, and consists of the eccentric proper and a boss to reinforce the shaft hole; this boss usually being on but one side of the casting. In Fig. 142, A is the center of the eccentric and B the center of the shaft.

Small eccentrics, especially those having a throw less than the diameter of the shaft, may be finished in the following manner: The casting is grasped in an independent chuck, one having four jaws being preferred, with the boss or hub running as nearly true as possible. The projecting face of the eccentric, together with the outside and face of the hub, may be machined, and the hole can be trued up with a boring tool or by the use of the chuck drill and reamer. In either case, it is advisable to obtain the exact diameter by using a finishing reamer. The eccentric may now be placed on a special mandrel, shown in Fig. 143, which has an extra set of center holes. A line connecting these holes is parallel to the axis of the mandrel, and at a distance from it equal to one-half the throw of the eccentric. It is obvious that this mandrel is the equivalent of the shaft and lugs used in turning solid crank

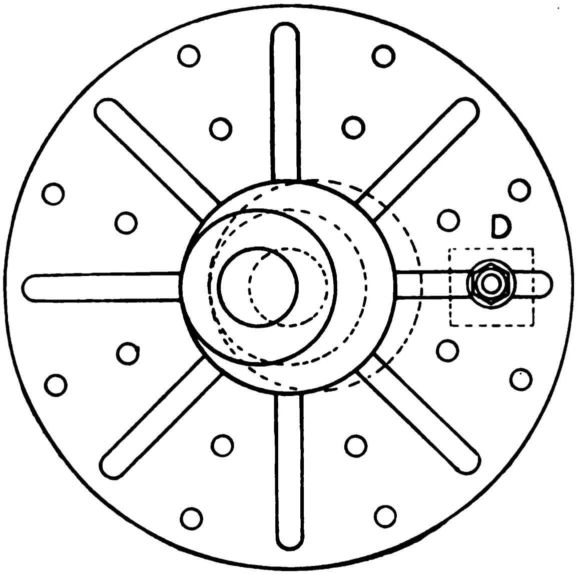


Fig. 144.

pins. On these extra centers the outside of the eccentric may be turned, and, on the regular centers, the back or plain face can also be finished. This completes the eccentric as far as the lathe is concerned.

Large and heavy eccentrics are preferably finished on a faceplate. The plain side or back having been previously machined, the eccentric is clamped to the faceplate with the hub running true, shown dotted in Fig. 144, and the face of the hub and the hole are finished as in the case of the small eccentric held in the chuck. The diameter of the hole being comparatively large, a reamer is not generally used. The eccentric is now moved on the faceplate a distance equal to one-half the throw of the eccentric, bringing the outer surface concentric with the lathe axis, as shown by the full lines, and the clamps placed so as to allow the outside to be turned. It is often necessary to balance the work by counterweights, in order to have the lathe run steadily. This is shown at D in Fig. 144.

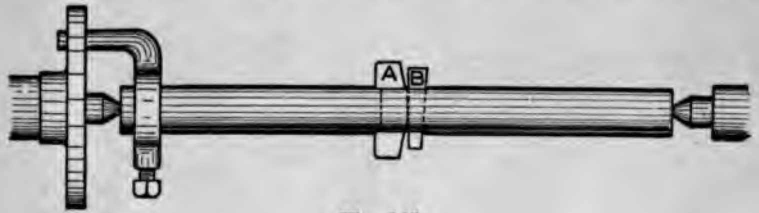


Fig. 145.

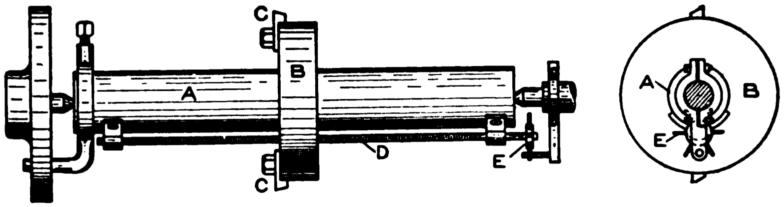


Fig. 146.

Boring. The boring of holes sometimes calls for a length and strength of tool that cannot be readily attained with the ordinary boring tool. A great deal of such boring is done with double-headed tools. These tools are held in bars and cut at each end. An ordinary form of such a tool is shown in Fig. 145.

The tool A is turned and fitted so that when placed in the bar it is central with the centers of the latter. It is held in position by the key B. It cuts at each end. Such a tool may be made to do very rapid work. It is extensively used for boring in places where a piece of work must be duplicated a great number of times.

Tools of this character are used for finishing. After the cut has been started the tool should not be stopped until the cut has been completed. If it is stopped there will be a ledge in the bore at that point. The reason for this is due to the springing of the metal and the contraction due to cooling while at rest. The tools used for finishing usually have a broad surface. Those used for the roughing-cut are narrower; they wear more rapidly than the finishing tools and are usually adjustable. A roughing tool may be held by a wedge as shown at B. Such a tool is placed in position and the wedge tightened just enough to hold it. The adjustment of the tool is then obtained by tapping it with the hammer. It is then held firmly by driving the wedge. An excellent example of this style of work is found in the boring of engine cylinders. Special machines are used for such work. The greater portion of it, however, is done in an ordinary lathe with a boring bar, as shown in Fig. 146. It consists of a heavy bar A, upon which there is a stiff traveling head B. The latter carries the tool C, which may or may not be capable of a transverse adjustment. The head moves longitudinally over the bar and is held,

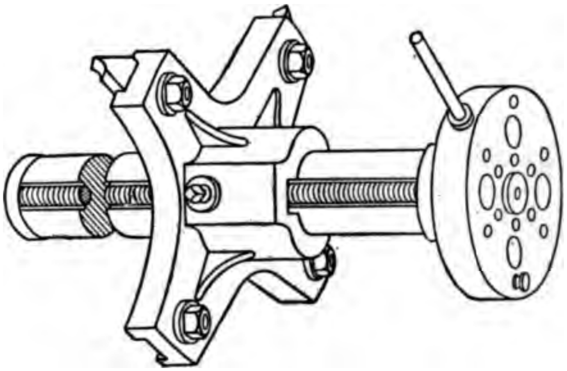


Fig. 147.

adjusted and fed by the screw D. At one end of the screw there is a star wheel, E, by which it is turned. As the bar revolves, one arm strikes against a stop at each revolution. This turns the screw by an amount proportional to the number of arms in the star. For example, if there are six arms in the star, the latter will be turned one-sixth of a revolution for each revolution of the boring bar. As the screw turns, it moves the head along the bar by an amount proportional to the pitch of its thread and the rays or arms in the star. This forms the feed of the tool. For example, if a star has four arms, and is keyed to a screw of eight threads to the inch, then for each revolution of the bar the head will be advanced $\frac{1}{32}$ of an inch. Another form of boring bar is shown in Fig. 147.

Boring bars with fixed tools are also used. In such cases the work is caused to travel beneath the bar as it is turned. A case of this kind occurs in the boring out of brasses for railroad cars.

It may be stated that, in general, all metal work should be finished in the position which it is eventually to occupy. This is due to its tendency to spring out of shape under the influence of its own weight. For small articles this influence is inappreciable. For large pieces it is sometimes quite apparent.

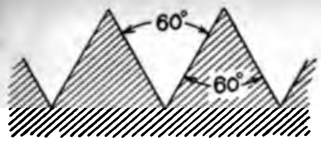


Fig. 148.

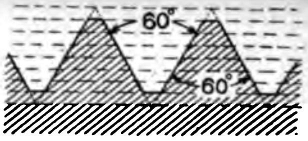


Fig. 149.

SCREW CUTTING.

The tools used for cutting threads are called *screw-cutting tools.* These tools are used in the lathe in the same manner as the diamond point and round-nosed tools. The cutting edge of the tool must be of the same shape as the space between the finished threads.

There are five types of screw threads commonly used in this country: the V thread, shown in Fig. 148, has the form of an equilateral triangle with an angle of 60°. It is sharp at the top and bottom. This thread is difficult to cut because of the trouble experienced in keeping the point of the tool sharp.

A modified form of V thread, known as the Sellers, the Franklin Institute, or the United States Standard, is shown in Fig. 149. This thread has an angle of 60°, with the top and bottom flattened for one-eighth of its depth. It is stronger than the V-shaped thread, and permits greater accuracy in cutting.

Another form in common use is the square thread. This is shown in Fig. 150. The thread and space are of the same width. These screws are used when heavy work is done, such as in jack-screws and presses.

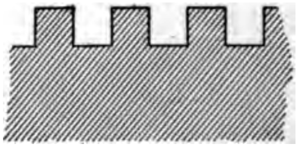


Fig. 150.

The Whitworth thread is similar to the United States Standard; the slight differences are as follows: the sides form an angle of 55° instead of 60°, and the top and bottom are rounded instead of flat.

The fifth type, the Acme thread, is similar to the square form. The difference is that the sides incline $14\frac{1}{2}$° from those of the square thread. This form of thread is much used for lathe lead screws and for giving motion to sliding parts of fine instruments, because the thread is much stronger than the square form, and the lost motion can be taken up by simply closing the nut halves nearer together.

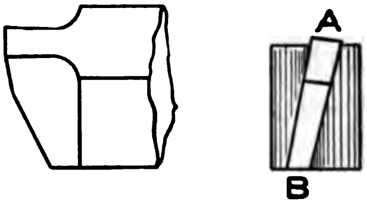


Fig. 151.

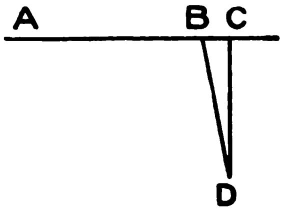


Fig. 152.

The tool used for cutting square threads is shown in Fig. 151. It is of the proper thickness at the cutting edge, but is somewhat narrower back of this point. The sides of the tool are inclined to the body, as shown at A B, Fig. 151; the amount of this inclination varies with the pitch of the thread and the diameter of the piece on which the thread is to be cut. To find the inclination, draw an indefinite straight line A C and at right angles to it draw C D. Make the length of C D equal to the circumference of the thread to be cut, measured at the root of the thread. On A C lay off from C a distance (B C) equal to the pitch; then draw B D. This line will represent the angle of the side of the thread. The angle of the side of the cutting tool must be a little greater for clearance.

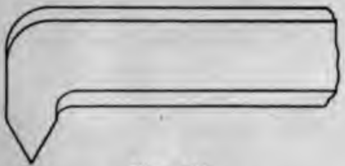


Fig 153.

For cutting *inside* threads, the shape of the cutting edge of the tool should be the same as for cutting an outside thread, but the tool must be made so that the cutting edge alone touches the work. This is accomplished by bending the tool as shown in Fig. 153 and giving it considerable clearance.

Standard Screw Threads. When screw threads are to be cut, the pitch used depends upon the outside diameter of the bar. A standard has been adopted by all of the leading technical societies of the United States, and is known as the United States Standard. The table (see opposite page) gives the outside diameter of the screw from ¼ inch to 6 inches in diameter, with the number of threads per inch to be cut.

In placing the tool for any form of thread, the point of the tool must be exactly level with the center, and a line at right angles to the axis of the lathe must bisect the angle of the tool point. In order that these conditions may be fulfilled, a thread or center gauge, Fig. 154, is used. In this tool, the angles, A, B, and C are made exactly 60°. The two opposite sides are parallel. The angle A at the end is used for grinding the tool. The sides of the latter are made to touch all along the edge. For setting the tool, the upper parallel side is held against the face of the work in a

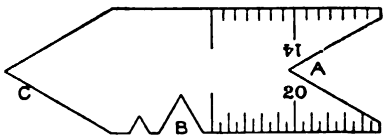


Fig. 154.

horizontal position. The tool is then set so that its sides touch along the edges of the notch B. The angle C is used to gauge the thread after it is cut.

UNITED STATES STANDARD SCREW THREADS.

Diameter of Screw in Inches.	Number of Threads per Inch.	Diameter of Screw.	Number of Threads per Inch.
¼	20	2	4½
5/16	18	2¼	4½
⅜	16	2½	4
7/16	14	2¾	4
½	13	3	3½
9/16	12	3¼	3½
⅝	11	3½	3¼
¾	10	3¾	3
⅞	9	4	3
1	8	4¼	2⅞
1⅛	7	4½	2¾
1¼	7	4¾	2⅝
1⅜	6	5	2½
1½	6	5¼	2½
1⅝	5½	5½	3⅜
1¾	5	5¾	2⅜
1⅞	5	6	2¼

The measurement of fine threads is a difficult matter where an ordinary rule is used and the threads between the inch marks are counted. For this purpose a pitch gauge, Fig. 155, is used. The gauges are short screw sections on thin sheets of metal. To ascertain the pitch of any thread, set the gauges over it successively until one is found that exactly fits. The figures stamped thereon will give the number of threads per inch.

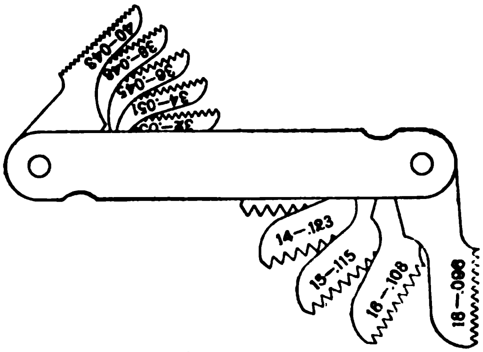


Fig. 155.

The cutting of a thread demands that there shall be a certain definite ratio of motion between the rotation of the work and the travel of the carriage. When a right-handed screw is to be cut, the carriage travels from right to left. For example, if a screw having a pitch of ¼ inch, or with four threads to the inch, as it is usually expressed, is to be cut, the spindle must make four revolutions while the carriage is moving one inch along the bed. If the screw is to have eight threads to the inch, the spindle must make eight revolutions to each inch of motion of the carriage or tool; if six threads, then six revolutions to the inch of motion, etc.

If, then, the lead screw is cut with four threads to the inch, it is evident that the speed of rotation of the spindle and of the screw must be the same, in order to cut a screw of four threads to the inch. For each revolution of the lead screw, the carriage moves the distance of the pitch of the same or ¼ inch. Hence, the gears, J and L, Fig. 91, must have the same number of teeth. When a screw of eight threads per inch is to be cut, the spindle must make twice as many revolutions as the lead screw. Then, for each revolution of the spindle, the lead screw makes half a revolution and thus moves the carriage ⅛ inch. In this case, the screw gear L must have twice as many teeth as the spindle gear J. For six threads, the ratio of revolutions between spindle and screw is 1½ to 1. This requires 1½ times as many teeth in the screw gear L as in the spindle gear J.

The rule for finding the gears to be used on the spindle and lead screw is: Multiply the number of threads on the lead screw and the number of threads to be cut by the *same* number; the products will equal the numbers of teeth on the gears to be used.

Suppose the lead screw has four threads per inch, and ten threads per inch are to be cut. Multiply both numbers by any convenient number, such as 3. Then the gears should have 12 teeth and 30 teeth.

Let a = the number of threads per inch on the lead screw,
b = the number of threads per inch to be cut,
c = a convenient number,
$a\,c$ = the number of teeth of gear on spindle,
$b\,c$ = the number of teeth of gear on lead screw.

If the gears thus found are not at hand, multiply by some other number. Thus, suppose gears of 30 and 12 teeth were not available, multiply 4 and 10 by 4 or by 5 or any other number that would give the number of teeth on the gears at hand.

Another way to find the gears is to remember that the number of threads to be cut is to the number on the lead screw as the number of teeth on the screw gear is to the number of teeth on the spindle gear.

EXAMPLES FOR PRACTICE.

(1) The lead screw has a pitch of ¼ inch. What is the ratio of gears to be used to cut a screw with 9 threads to the inch? If one gear has 24 teeth, how many should the other have?

$$\text{Ans.}\left\{\begin{array}{l}1:2\frac{1}{4}\\ 54\text{ teeth.}\end{array}\right.$$

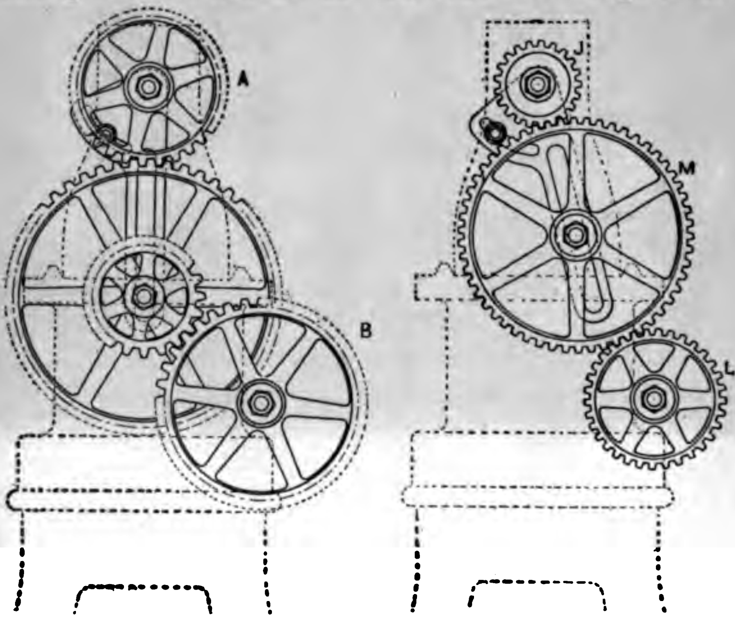
(2) The lead screw has a pitch of ¼ inch. What is the ratio of gears to be used to cut a screw with 16 threads to the inch? Ans. 1: 4.

(3) The lead screw has a pitch of ⅓ inch. What is the ratio of gears to be used to cut a screw with 12 threads to the inch? Ans. 1: 4.

In these cases the actual number of teeth on the gears to be used is obtained by multiplying the ratio by some common multiple. Thus in example 1, multiplying by 10 gives 40 teeth for the spindle gear and 90 for the screw gear. In example 2, multiplying by 20 gives 20 teeth for the spindle and 80 for the screw gear; and the same result is obtained by using the same multiple for example 3.

Every screw-cutting lathe is provided with a set of gears from which selections can be made. In order to facilitate the choice of the gears to be used, a *gear table* is usually cast in raised letters and screwed to the front piece of the headstock. This table shows the gears to be used for cutting such threads as may be enumerated on the table.

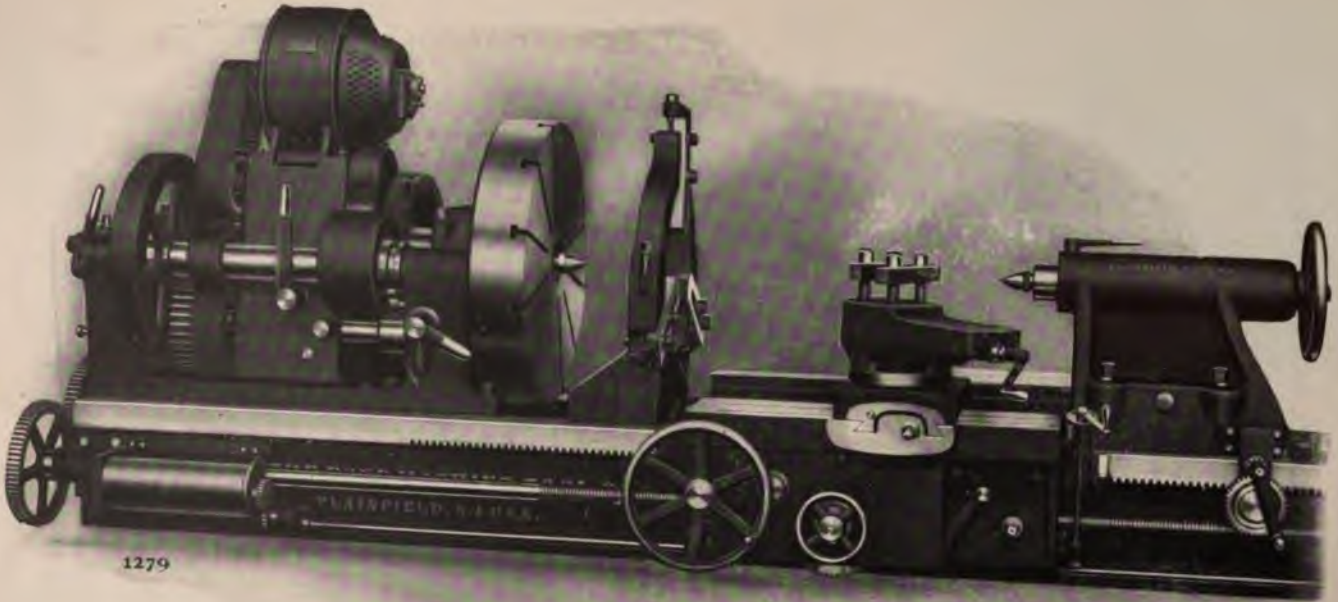
It is sometimes necessary to cut a screw for which there are no gears to make a direct connection. This necessitates the compounding of the gears on the intermediate spindle to replace the single gear. This is done as shown in Fig 156, in wnich A represents the spindle and B the screw. Suppose, with a lead screw having three threads to the inch, it is desired to cut a screw having thirteen. This makes the ratio of teeth on the spindle gear to those on the screw as 3 to 13. The work can be done with spindle gears having 15, 30, or 45 teeth with screw gears having 65, 130, and 195 teeth respectively. If it is found that there are no gears having 15, 45, 130, or 195 teeth on hand, compounding must be resorted to. To determine the gears to be used it must be remembered that *the product of the numbers of teeth in the driving gears must be to the product of the numbers of teeth of the driven gears, as the number of threads per inch on the lead screw is to the number to be cut.* In this case it is as 3 to 13. Multiply each of these figures by any convenient multiple. In the example in hand, let the multiple be 200. Then



Compound Gear. Fig. 156. Simple Gear.

$$\frac{3 \times 200}{13 \times 200} = \frac{3 \times 2 \times 2 \times 2 \times 5 \times 5}{13 \times 2 \times 2 \times 2 \times 5 \times 5}.$$

Select from the factors thus obtained two sets, each of which, when multiplied together, will give products equal to the number of teeth that are on hand.



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42-INCH POND LATHE.
Niles-Bement-Pond Company.

Thus in the numerator we may take 3 × 2 × 5 and 2 × 2 × 5, giving 30 and 20 as gears that are to be used as the spindle and intermediate drivers respectively.

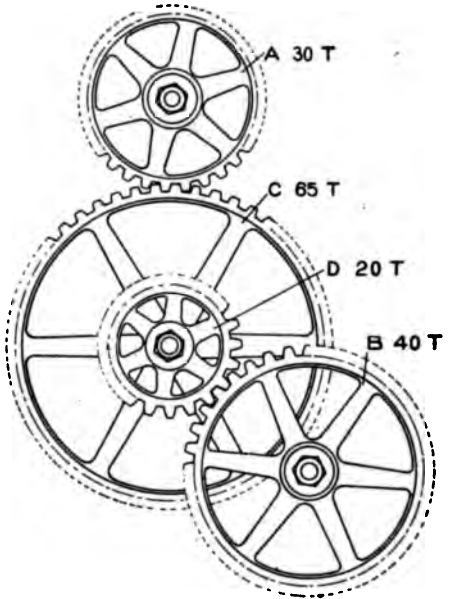


Fig. 157.

For the denominator take 13 × 5 and 2 × 2 × 5 × 2 or 65 and 40, for the driven gears of the intermediate stud and the screw respectively. Placing these in position as in Fig. 157, we have,

Gear A with 30 teeth.
Gear C with 65 teeth.
Gear D with 20 teeth.
Gear B with 40 teeth.

It is desired to cut a screw with 11 threads to the inch on a lathe having a lead screw with a pitch of ¼ inch. The gears available have 30, 40, 45, 50, 55, 60, 65, 70, 80, 90, and 100 teeth respectively. What ones are to be used and where?

Ans.	Spindle	40 teeth
	Intermediate driven	55 teeth
	Intermediate driver	50 teeth
	Screw	100 teeth.

Many screw-cutting lathes are not made with an extension of the spindle to receive the first gear, but a short shaft or stud projects from the headstock for this purpose. This stud is geared to the spindle, and the ratio of this gearing must be considered when calculating the gears for screw-cutting. For example, suppose we wish to cut twelve threads per inch in a lathe having a lead screw with eight threads per inch and a ratio of two to one between the spindle and the stud. In other words, the stud runs half as fast as the spindle. As we have seen in the previous examples, the ratio between the spindle and the lead screw must be 12 to 8.

The first gear is not attached to the spindle, but to the stud, which makes six revolutions to twelve of the spindle. Therefore, the ratio between the stud and the lead screw, where the gears are actually applied, must be 6 to 8. Multiplying by 6 will give 36 and 48 as the number of teeth in two gears which may be used.

In general, the data that must be given to calculate the change gears for screw-cutting are the number of threads per inch to be cut on the work, the number of threads per inch on the lead screw, and the speed ratio between the spindle and the stud, if a stud is used.

The following examples may be taken as applying to either right- or left-hand threads. The change of direction in the travel of the carriage is obtained by introducing an extra gear into the train, thus reversing the rotation of the lead screw.

The foregoing description of the method of cutting a "V" thread will suffice to illustrate the cutting of any form, with the slight changes which are necessary in the other forms due to the shape of the tool employed.

To cut an ordinary V thread, a V-pointed tool having an angle of 60°, and set so that a line at right angles to the lathe axis bisects the tool angle, and also set exactly at the height of the center, is caused to move at a constant rate parallel to the work surface, while the work is being uniformly rotated.

The relation between the rotary motion of the work and the lateral movement of the tool, determines the pitch of the thread being cut, and the mechanism connecting the work and the tool must be of a positive character; thus eliminating transmission by belts and other frictional devices.

Owing to the lost motion or "back lash" in the mechanism connecting the tool and the work, the tool cannot be returned to the starting point for a new and deeper cut by simply reversing the lathe. The tool must be withdrawn, the lathe reversed, the tool returned to the starting point, and then advanced for the new cut. To place the tool for the new cut with accuracy, a stop or graduated device is provided.

If removed from the lathe for testing, care should be taken in replacing the work to get the tail of the dog in the same slot in the face plate that was used to cut the original thread; this can be done by marking or otherwise indicating it.

Chasing. The ordinary methods of cutting screws have already been described. Where great accuracy is not necessary, the threads may be chased by hand. A chaser, or chasing tool, differs from the ordinary thread-cutting tool, in that it has a number of cutting points instead of but one. When a chaser is operated by a power feed, it is customary to have a shaft revolving at the same rate or at an even multiple of the rate of the lathe spindle. This shaft carries a master thread into which a section of a nut drops. The handle connected with the nut carries the chasing tool. When the nut is in contact, the tool is cutting. At the end of the cut, the tool is lifted out, and with it the nut disengages with the thread.

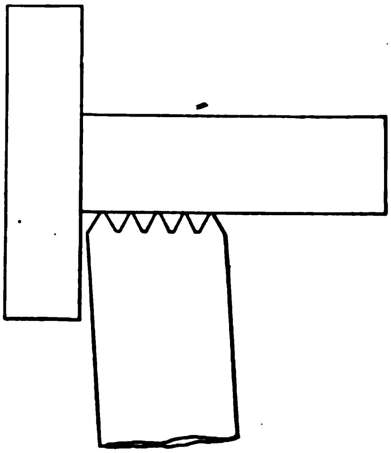


Fig. 158.

Hand-chasing requires a great deal of skill in order that a good piece of work may be done. The chasing tool has a number of points as shown in Fig. 158. The work must be run rapidly in the lathe. The tool is held in both hands, and is supported on a rest similar to that shown for the hand-turning tools in Fig. 86. The first left-hand tooth of the chaser is brought lightly against the right-hand edge of the work. The handle is given a quick twist from left to right throwing the teeth in the opposite direction. It is well after the first twist, to stop the lathe and examine the

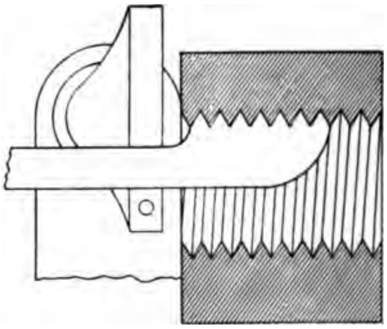


Fig. 159.

work. If the operation has been properly performed, the second tooth will be found to have entered the groove made by the first. A short length of thread will have been cut, the pitch being the same as that of the chaser. If this is correct, the lathe may again be started and the chaser applied as before. On the second trial the thread may be run to its full length. The finishing of the thread is done by merely repeating the operation. A fine cut is taken with each application of the chaser for the whole length of the thread until the full depth has been cut. In doing this work, the rear or right-hand side of the chaser should be pressed more firmly against the piece being cut than the front, because the threads with which that portion of the tool is engaged are more deeply cut than at the front. In addition to cutting, these teeth also guide the front. The reason for running the lathe at a high rate of speed, is that the movement of the chaser is less likely to be checked or thrown aside by seams or inequalities in the density of the metal than it would be if the lathe were to run slowly. Inside threading may be done by means of the inside chaser shown in Fig. 159.

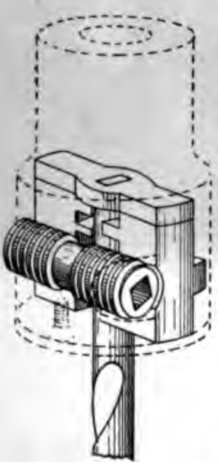


Fig. 160.

Drilling in the Lathe. The lathe can also be used for drilling. When such work is to be done, the drill may be held in the spindle and the work forced up against it by the screw of the tail stock: or the work may be revolved and the drill forced in by the tail-stock screw. When the first method is followed the drill may be put into a socket prepared for it in the spindle of the lathe, or the drill may be held by a drill chuck as shown in Fig. 160. This chuck may be used in the tail-stock to hold twist drills, or to hold flat drills which are forged from round stock. Flat drills made from flat stock are centered at the rear end and held against, and fed forward by, the dead center. In this case, a slotted rest held in the tool post prevents the drill from turning (see Fig. 60) and aids in starting the drill true.

When the drill is held in the head stock, the work may be fastened to the carriage and fed against the drill, or it may be held by means of a suitable device held in the tail stock. For this purpose the drill pad, shown in Fig. 161, may be used, and especially if the work be flat. The V center, shown in Fig. 162, is used when it is desired to drill through the axis of a piece of round stock. The shape of the groove prevents the work from turning and the angle being always in the axis of the lathe determines accurately the location of the hole.

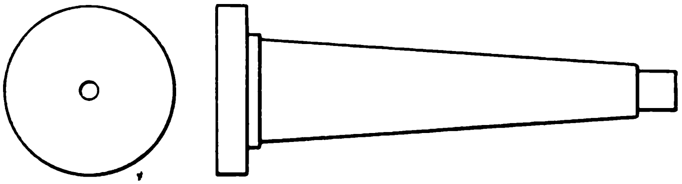


Fig. 161.

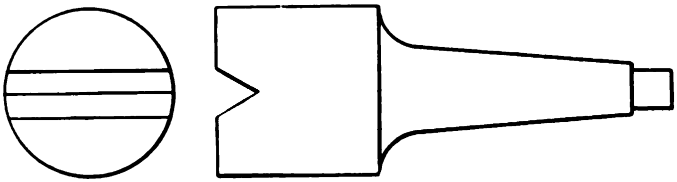


Fig. 162.

THE DRILL PRESS.

This tool is made in a great variety of forms, according to the class of work it is intended to perform. The form illustrated in Fig. 163 is one of the standard makes. The mechanism is very simple and will be briefly explained.

The frame consists of a strong column A, securely bolted to a heavy base-plate B. Power is delivered to the machine by means of a belt running over the cone pulley C. The shaft upon which this cone pulley turns, runs through the casing D, where, by means of miter gearing, it drives the vertical drill spindle E. It will be seen that there are four steps on the cone pulley C, thus affording a means for securing as many rates of revolution of the drill spindle. This, however, is not sufficient to meet all the

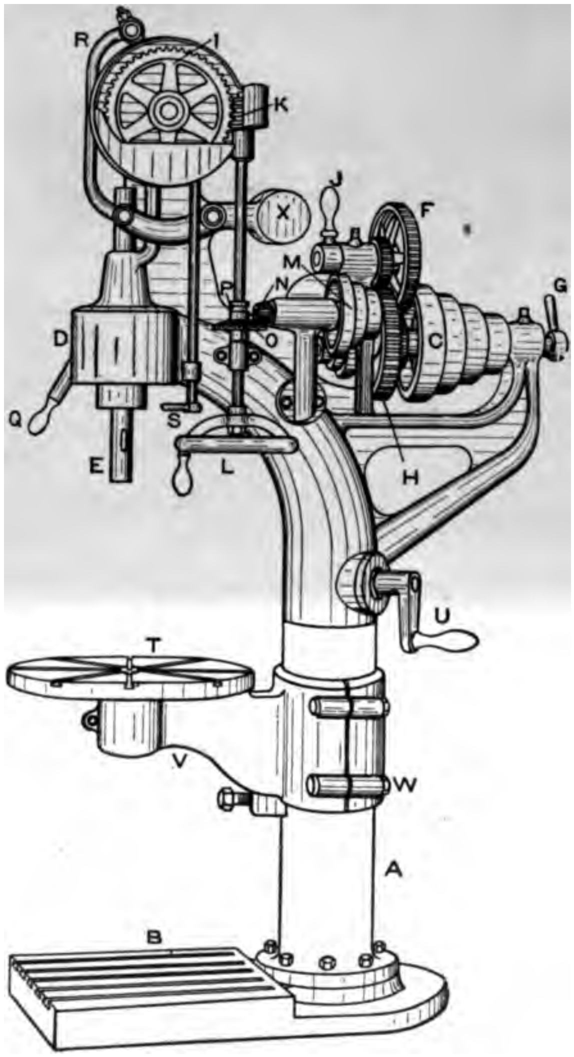


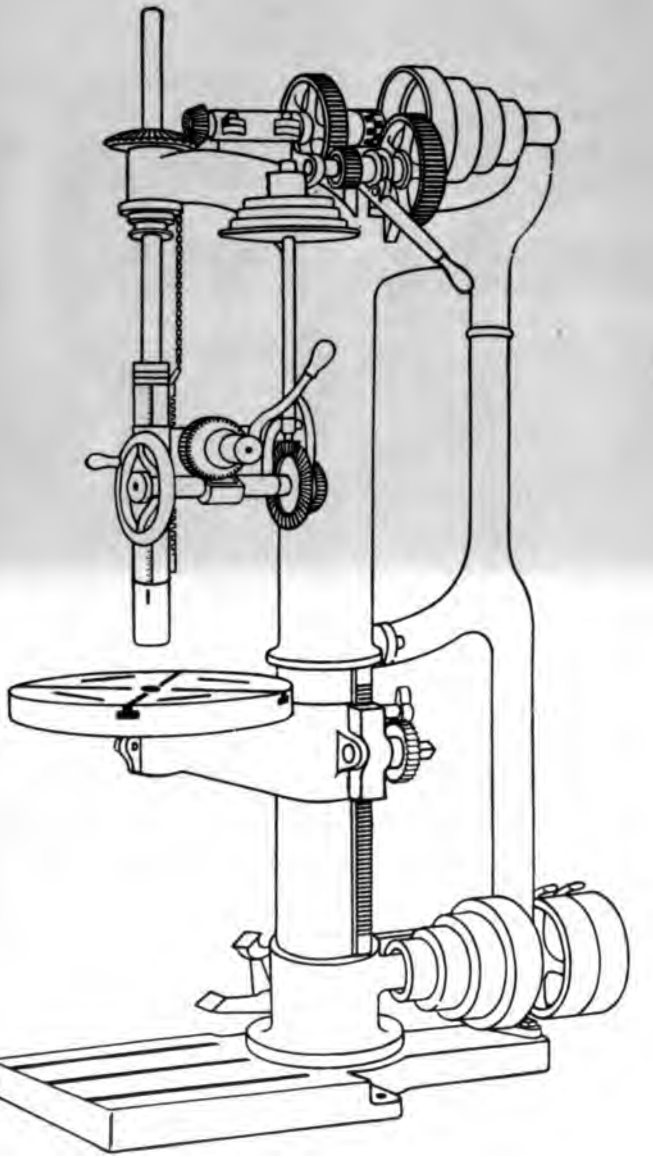
Fig. 163.

requirements of the work that can be done with the tool. In order to increase the range of available speeds, a *back gear* is used. This is shown at F. It consists of a gear and pinion keyed to the same shaft. The cone pulley C is loose on the horizontal shaft, but may be fastened to it by a clutch operated by the lever G. The inner end of the cone pulley carries a pinion that meshes with the gear F, while the pinion attached to F meshes with the gear H that is keyed to the horizontal shaft. The gear F and its pinion run loosely on a journal that is, in turn, attached to an eccentric bearing. By turning the handle J, which is attached to the eccentric bearing, the gears may be thrown in or out of mesh. While the gears are in mesh, the power passes from the cone pulley to the pinion attached to it, to the gear F, to its pinion, and thence to the gear H, and thus turns the shaft. Under these circumstances the shaft is turning much slower than the cone pulley.

The feed, or downward motion of the drill spindle may be accomplished by hand or by power. At the upper end of the drill spindle a rack is cut, into which a pinion on the same shaft as the worm wheel I meshes. It is evident that, as this wheel revolves, the spindle will be raised or lowered.

The weight of the spindle is counterbalanced by the weight X. The worm wheel I is turned by the worm K, which is rotated by the hand wheel L. This serves for a hand feed. For a power feed, a belt is made to drive the cone wheel M. This turns the bevel pinion N, meshing with the bevel gear O, that is loose on the feed shaft. It is fastened to the latter by means of a small clutch P. A quick return of the spindle is accomplished by means of the handle Q. This is attached to the spindle by means of a yoke R. When the quick return is to be used, the worm K is thrown out of mesh with its wheel by turning the handle S.

The table T may be raised or lowered by means of the handle U; this drives a screw in the standard running in a nut fastened to the bracket V. When the table has been adjusted, it may be fastened by the nuts and bolts W clamping it to the standard A. When large work is to be drilled, the table may be swung out of the way and the work bolted to the base plate B.



[illegible]

While the drill press just described may be taken as representing good practice in the smaller sizes, a different form of construction is often employed in larger tools. A drill press of this class is shown in Fig. 164. Drilling machinery is made both horizontal and vertical. A typical form of the horizontal variety is shown in Fig. 165. These tools are usually of heavier construction and for a larger class of work than the ordinary vertical drill.

Drilling machinery, both horizontal and vertical, is sometimes provided with more than one spindle. In small vertical drills of this description, the spindles are fixed in their relative positions and are not intended to be operated simultaneously; the work is passed from one spindle to another. The true multi-spindle drill is for the purpose of drilling several holes at one time and in any relative position within the limits of adjustment of the machine. Such a drill is shown in Fig. 166.

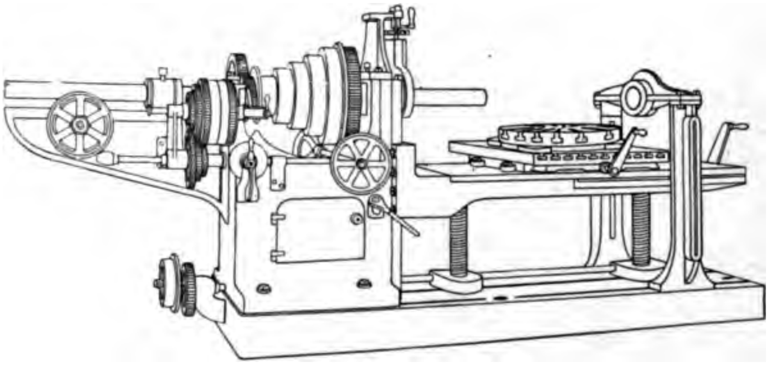


Fig. 165.

The Radial Drill. Another form of drill, known as the radial, is being extensively used. It is shown in Fig. 167.

The drill spindle is carried on the arm A. It is so arranged that it can be set and run at any position on this arm. At the same time, the arm may be swung around and clamped in any vertical or horizontal position about the upright B. These drills are usually employed on heavy work, where a number of holes are to be drilled.

In the case of the drill shown in Fig. 163, the work is ordinarily light, and can be readily shifted so that the position of the holes can be brought beneath the drill. In heavy work, such as engine cylinders, however, this cannot be done. It is, therefore, necessary to be able to shift the drill and place it in a position to do the work. The radial drill affords the means of doing this. When the vertical spindle carrying the drill can be rotated in the vertical plane, holes can be drilled, not only in any position, but also at any angle. Such a drill is called a Universal Radial.

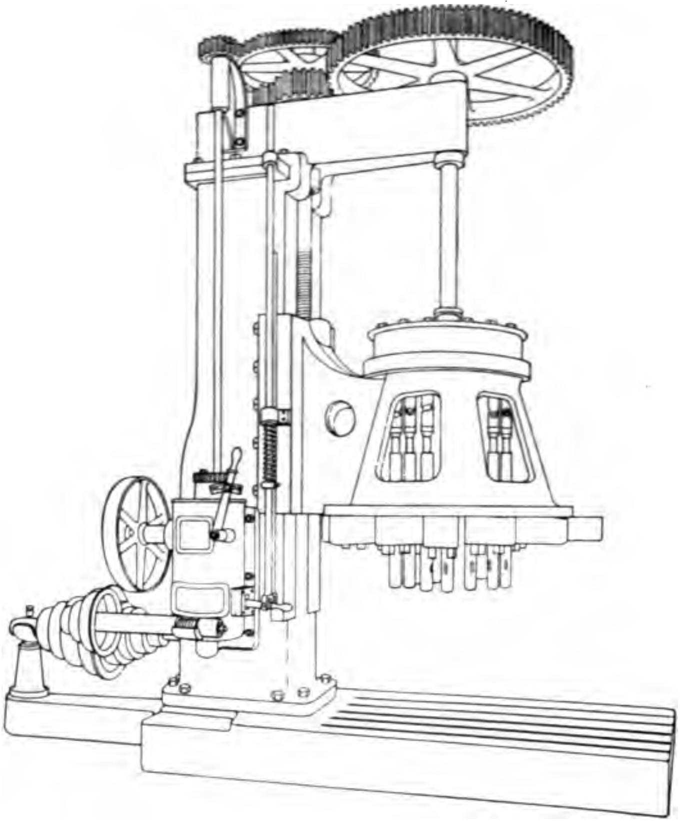
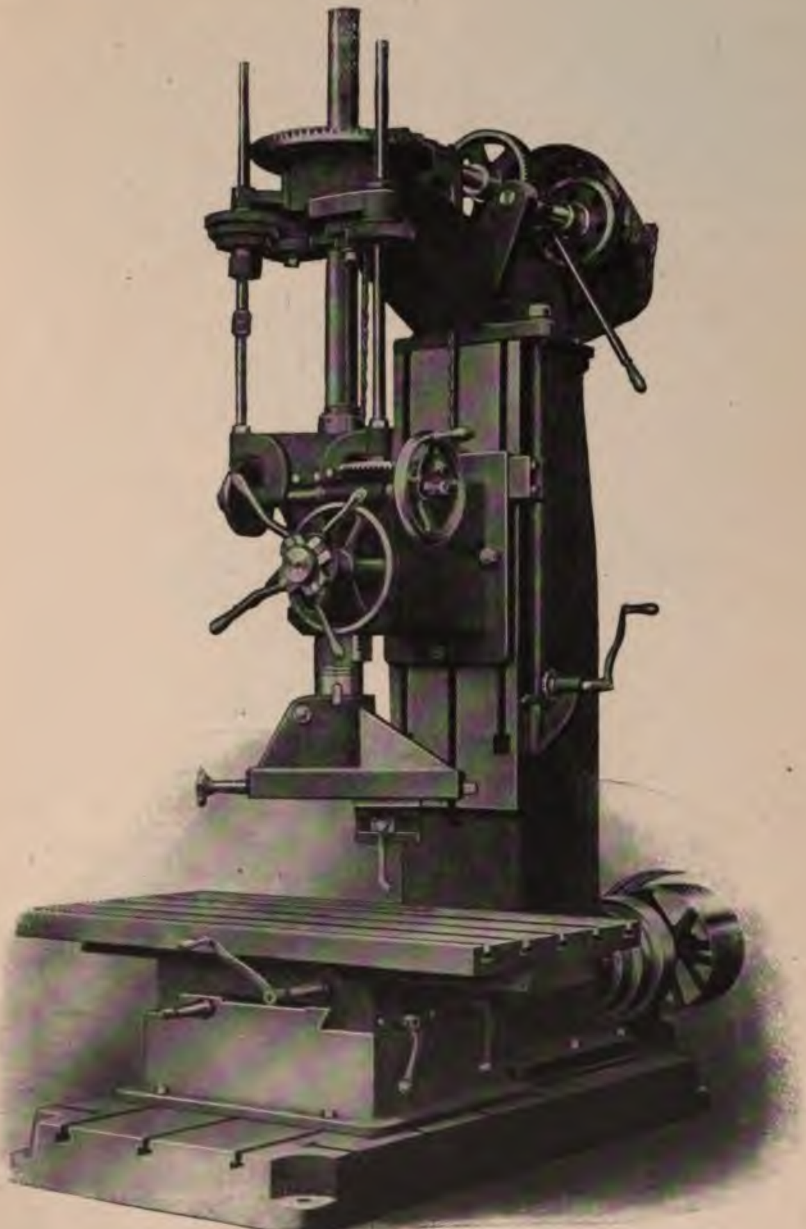


Fig. 166.

The position of the holes is usually laid out for the guidance of the man at the drill. The work is best done as shown in Fig. 168. The center punch mark, indicated by A, shows the



DRILLING, BORING, AND TAPPING MACHINE.
Dreses Machine Tool Co.

location of the center of the hole. The circle upon which the prick punch marks BBBB are placed, gives the location of the circumference of the hole. To drill the hole, place the point of the drill in the center punch mark A, and drill into the metal until the center punch mark has been slightly enlarged, as shown by the circle C, Fig. 168. Then raise the drill and examine the work. If the countersink or hole, whose circumference is indicated by the circle C, is exactly concentric with the outer circle BBBB, then the drill may be put down and the hole drilled.

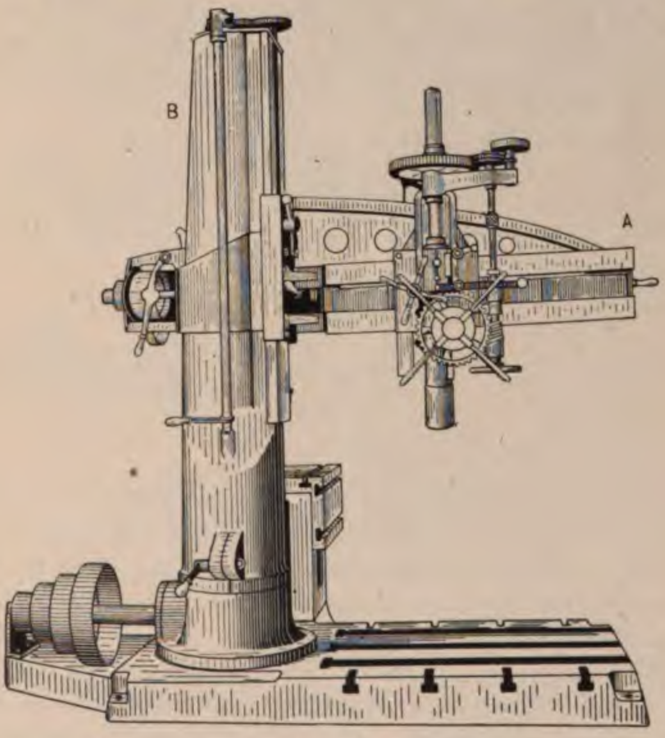


Fig. 167.

Owing, however, to various causes, it is not often that the circle will be concentric. This may be due to an uneven grinding of the drill, a distortion of the metal by the center punch, or an eccentric motion of the drill point, due to a lack of truth in the running of the spindle.

When the countersink is not concentric, the drill must be drawn back to the central position. The method employed is shown in Fig. 169. The round-nosed chisel is used to cut a groove, E, down the side of the countersink, on the side that is farthest from the circle BBBB. The depth of this groove depends upon the amount of eccentricity of the countersink and the depth to which it has been drilled. The drill is then run down again and the groove drilled out. The action of this groove is as follows: as the drill turns, one cutting edge is supported, and is working into the face C, Fig. 170. At the same time the cutting edge is opposite the groove E. The drill, therefore, springs into the groove, as shown. The lip then catches on the edge of the groove and cuts it away, making the hole elliptical, and shifting the center of the drill towards its proper position. As the drill sinks deeper both lips are in contact with the faces C and D, and it has no further tendency to shift.

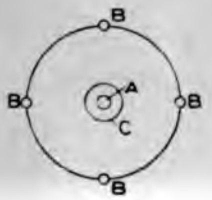


Fig. 168.

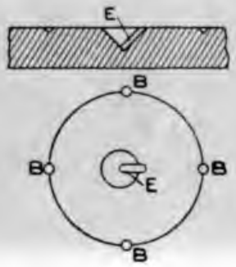


Fig. 169.

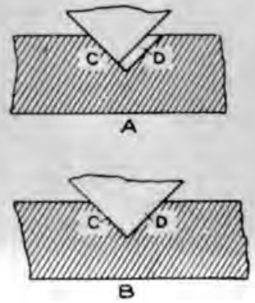


Fig. 170.

When the groove has been drilled out, the drill must be again raised, to ascertain whether or not the countersink is concentric with the outer circle BBBB. If not, another groove must be cut, and the process repeated. If it is, the hole may be drilled. The prick punch marks BBBB are put on the outer circle to indicate its position in case of the obliteration of the line itself.

A twist drill will usually clear its hole of chips. For deep holes this may not occur. It is then necessary to withdraw the drill and clean out the hole. This can be done by a piece of wire bent at the end; also by using a "blowpipe" made of a small tube, and bent to enter the hole, so that the chips will not blow up into the operator's face. Cast iron is more likely to need cleaning than wrought iron or steel. Where flat drills are used, it is always necessary to clean the holes at frequent intervals, as they have no tendency to raise the chips and clear the holes.

A matter to receive due consideration is that the work must be held rigidly on the table while being drilled. This may be done in two ways. If the holes are to be drilled with great accuracy, the work must be clamped to the table. This is often done by means of straps, as shown in Fig. 171. In this figure, a gland A is shown clamped to the table by the straps BB. One end of the strap rests upon the flange of the gland, and the other upon any convenient piece of metal C, of the proper thickness. The bolt D is put up through a hole in the table as close to the work as possible. When the nuts are screwed down, they then put the greatest available pressure on the work and hold it fast. The strap B is made of flat iron. It has one or more holes drilled in it to permit the passage of bolts.

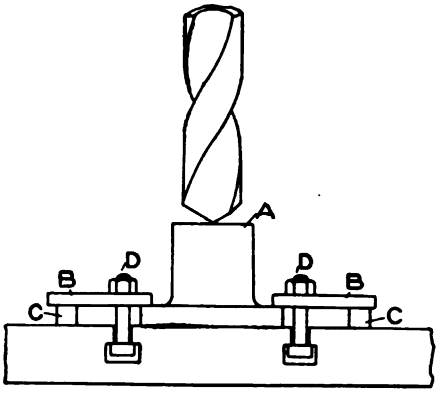


Fig. 171.

Another method of holding work in the drill press is by means of a post. This is shown in Fig. 172. It consists of a post A, set loosely in one of the holes in the table. As the drill is forced against the work, it tends to turn the latter with it. When the work strikes the post, it is stopped and held while the hole is drilled. This will not hold the work perfectly steady. It allows the latter to move with the eccentricity of the motion of the drill, but it is in very common use where extreme accuracy is not essential. For example, where a finished bolt is to be used with a driving fit, the work must be securely fastened so that the diameter of the hole may be true. Where a machine bolt made of rough iron is to be used, the hole is drilled $\frac{1}{16}$ inch larger than the normal size of the bolt. Here accuracy is not even attempted; a variation of $\frac{1}{32}$ inch in the diameter of the hole is of no account. Therefore, in such cases, the work may be allowed to merely rest against the post.

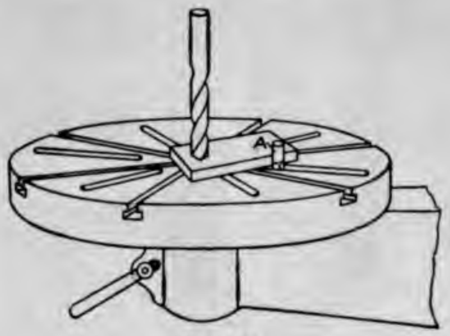
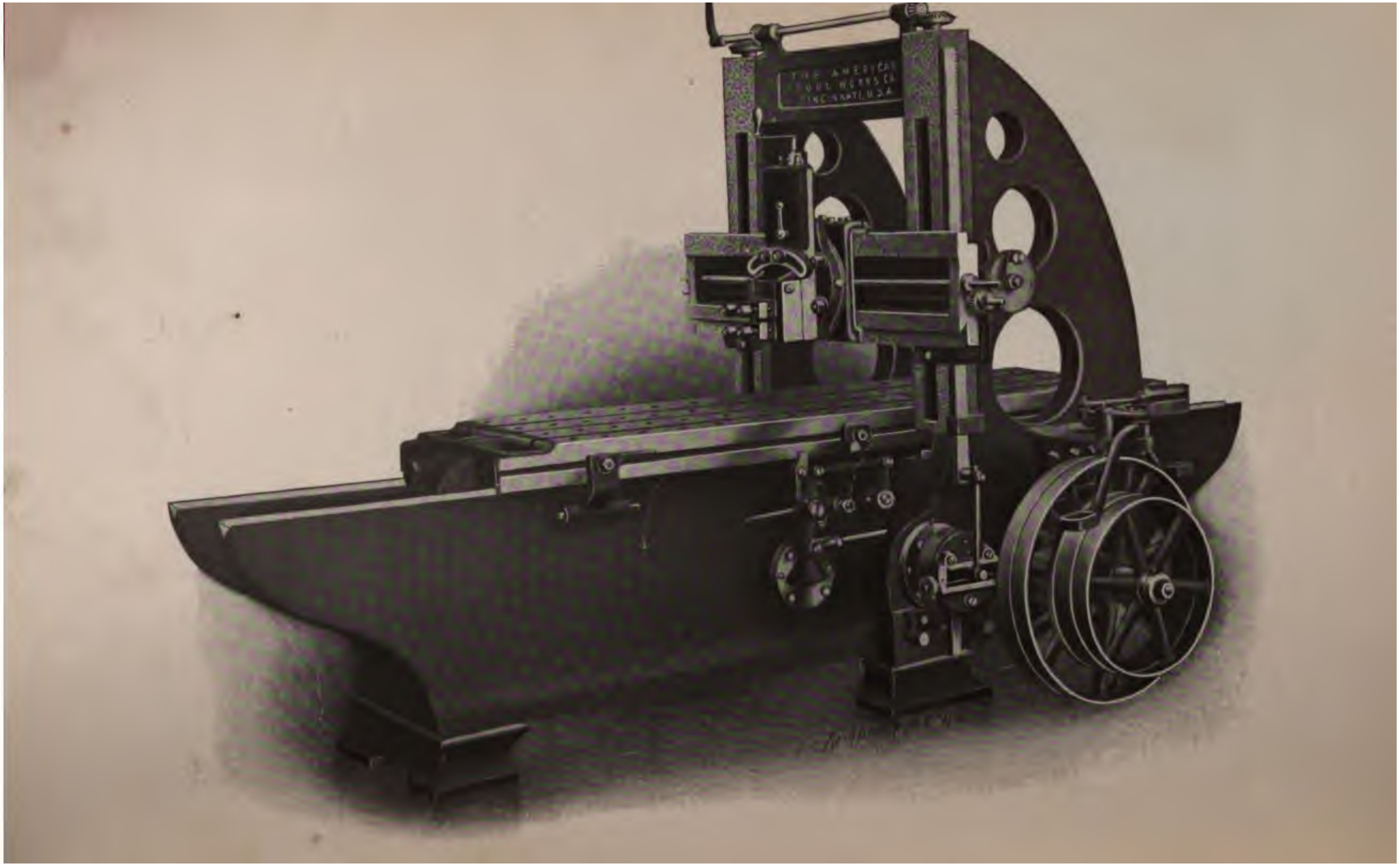


Fig. 172.

This question of holding the work does not apply to drills of the multi-spindle class. It is evident that the tendency of one drill to rotate the work is *counteracted by the action of another drill.* Therefore, no holding devices are needed on drills of more than one spindle.

An angle iron, forming a right angle with the drill table, is used in many cases where the hole cannot be properly located by the use of the table alone. The clamping to the angle iron must be very rigid to resist the pressure of the drill. A tilting table is sometimes used so that holes may be drilled at any required angle. At least one manufacturer is putting on the market a horizontal drilling machine which can drill five sides of a cube at any angle with but one setting of the work.

Drilling machines may also be used for tapping. This requires a reversing device for backing out the tap. The backing-out is done at a much higher speed than the tapping. The tap is held in a friction head that will slip when the tap strikes the bot-


THE AMERICAN
TOOL WORKS CO.
CINCINNATI, U.S.A.

tom of the hole. The use of collapsing taps, especially on diameters of one inch and over, renders the backing-out unnecessary and quickens the operation. Studs may be set by the same device, so that cylinder flanges may be drilled, tapped, and the studs set without removing the work from the drill. Duplicate drilling by means of jigs will be considered later.

THE PLANER.

Next to the lathe, the planer is the most important tool in the machine shop. As the name indicates, it is used for finishing flat surfaces. In the ordinary planer, the work is moved and the tool is at rest. A common form of this tool is shown in Fig. 173. It consists of a bed A upon the upper surface of which suitable guides or ways are planed. The platen B is made to travel back and forth upon these ways. The platen has a rack on its under surface into which the gear C meshes. This gear is driven by a train of gears from the shaft carrying the pulley D. The tool is carried on the tool-head E, where it can be given a slight vertical motion or feed. This tool-head may be fed across the machine by the screw in the cross-rail F. The latter may be raised and lowered by the shaft and gearing shown at the top. This gearing turns two vertical screws running in nuts attached to the cross-rail.

The reciprocating motion of the platen is obtained as follows: the pulleys D and G are driven in opposite direction by belts. Either one may be connected to the shaft on which they turn by a clutch which is operated by the bell crank lever J. On the platen there are two adjustable dogs HH. These are set so that, when the work has just cleared the tool in either direction, one of them will strike against the upper end of the lever I. In the illustration, if the platen is moving in toward the right-hand dog, H will have struck the lever. As the platen continues to move, the lever I is carried to the right and the clutch connection fastening the forward pulley to the shaft broken and that of the return made. The motion is then reversed and continues until the left-hand dog strikes the lever I and again changes the motion.

Ordinarily the tool cuts only when the platen is moving toward the right Fig. 173. As a result of this condition, the platen is made to move more rapidly in the direction of the arrow than in the reverse. This is accomplished by varying the speeds of the pulleys D and G. The usual ratio of the speeds of these pulleys is from 1 to 2, to 1 to 5.

The feed of the tool is accomplished by a friction clutch driving the vertical rack K. This acts only at a point near the end of the travel of the platen. It is so arranged that any vertical or horizontal feed may be given to the tool.

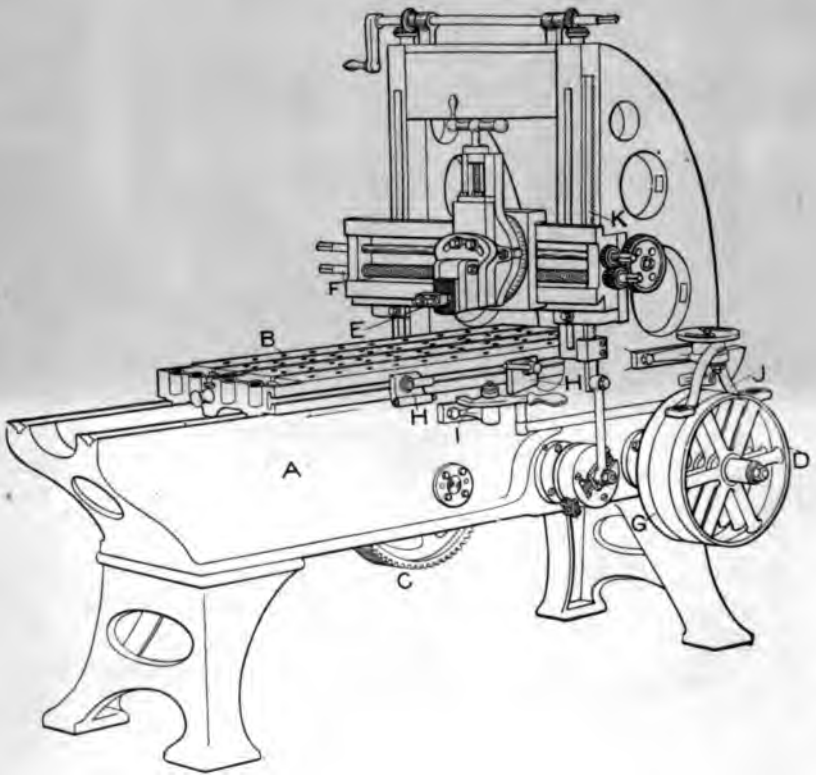


Fig. 173.

Planers are made in a great variety of sizes and styles. Very frequently there are three driving pulleys placed side by side on the same shaft, the central one of the three keyed to the shaft. The reversal of the motion of the platen is obtained by shifting one or the other of the belts onto the central pulley.

Planer Tools. The tools that are used upon planers do not differ essentially from those described for lathe work. The same rule applies regarding the holding of the tool. It should project as short a distance as possible beyond the point of support. When there is an excessive projection, care should be taken that the tool is so set that it will not spring into the work. On the lathe this can be prevented by setting the point of the tool on a line with the center. In Fig. 174 the tool tends to spring and turn about the point A as a center. The dotted line at the point shows how this tends to throw it into the work. The same thing is shown in the planer tool in Fig. 175. This tendency can be overcome by forging the tool so that the cutting point is behind a perpendicular from the point of support, as shown by the dotted lines in Fig. 175. In the latter case the spring of the tool tends to take it out of the work.

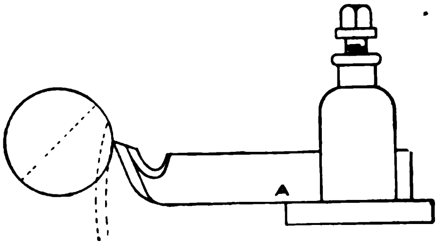


Fig. 174.

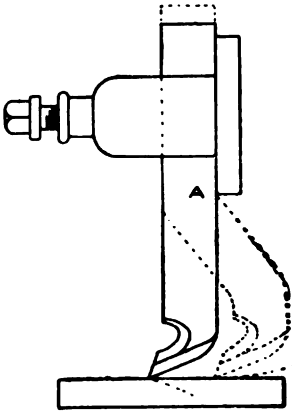


Fig. 175.

Holding the Work. The work is usually held on the planer by clamping it down with straps in a manner similar to that shown in Fig. 171. Where the whole upper surface is to be planed over, holes are sometimes drilled in the sides, into which the rounded ends of straps are set.

It is impossible to give more than general directions for clamping work on a planer. A great variety of blocking, clamps and bolts must be used; such attachments being suited to the work in hand, and requiring an outlay of money which seems to be out of proportion to the appearance of the collection. It should be sufficient to say that the work must be carefully set, strongly clamped and braced to prevent movement by the tool; the clamping should not distort the work. As all castings and forgings change their shape when the surface is removed, it is considered good practice to release the clamps before the finishing cut, in order that the piece may assume its final shape, and then reclamp it without distortion.

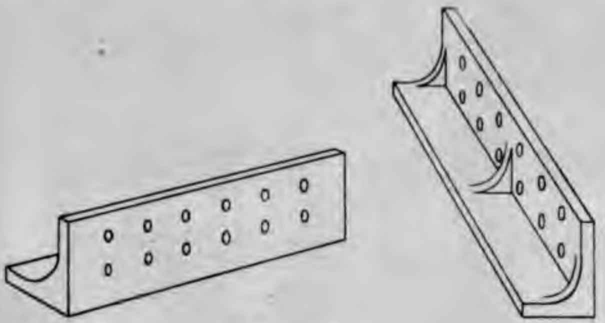


Fig. 176.

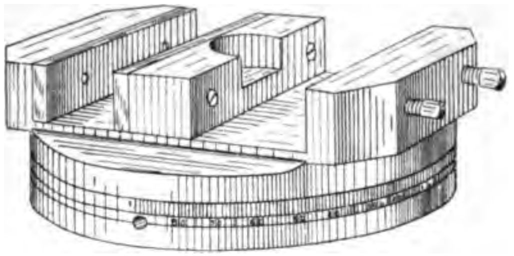
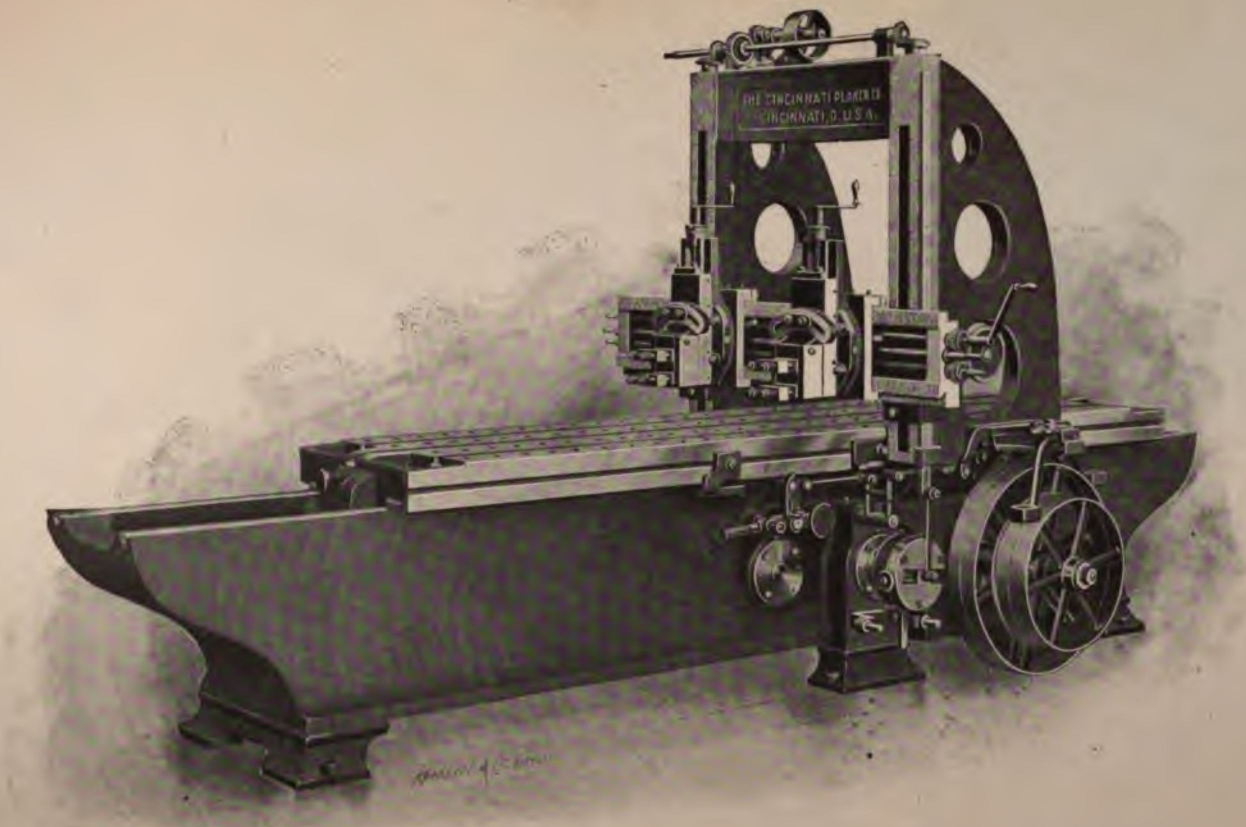


Fig. 177.

Angle irons or knees, as shown in Fig. 176, may be considered as an auxiliary table with a surface at right angles to the



36-INCH PLANER.
Cincinnati Planer Co.

main table. Many useful applications of these holding devices will suggest themselves.

Another method of holding work is by using a vise such as is shown in Fig. 177. The body is bolted to the platen and the work is held between the jaws.

Planer centers, as illustrated in Fig. 178, are very useful in machining parts where accurate circular spacing is desired, or where projecting lugs prevent turning in the lathe.

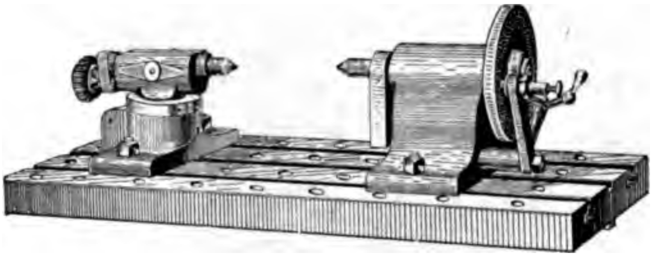


Fig. 178.

The Plate Planer. A special form of planer extensively used in boiler shops and shipyards is the plate planer, Fig. 179. It is used for planing the edges of long plates. The plate is securely fastened between the clamps A and the bed B. The tool is held in the carriage C, which is moved to and fro by the screw D. The screw is driven by the gear H, that meshes with a pinion keyed on the shaft to which the motor is geared. The reversal of motion is obtained by shifting the clutch K. The tappets M for moving the shifting gear are upon the shaft I. They are struck as the carriage approaches the end of its stroke. Unlike the ordinary machine shop planer, the plate planer has no quick return stroke, but has a tilting tool which allows stock to be removed when moving in either direction. Devices of this character have often been tried on regular metal planers, but seem to be satisfactory only when the whole face of the work can be covered at a single stroke of the tool.

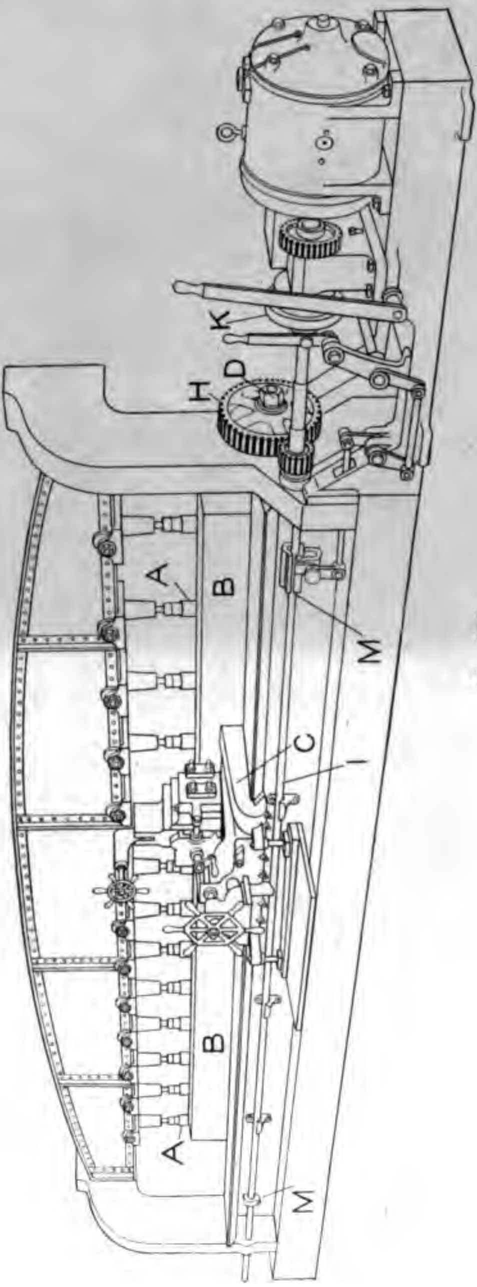
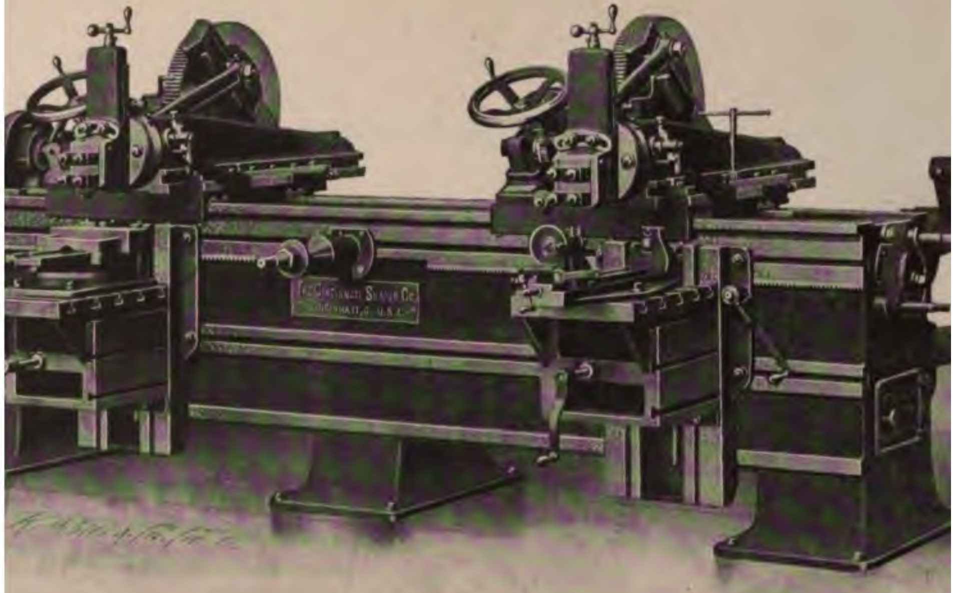


Fig. 179.



TRAVERSE SHAPER.
The Cincinnati Shaper Company.

THE SHAPER.

For light work the shaper or shaping planer, Fig. 180, is extensively used. It possesses the advantage of rapidity of action. In this machine, as in the plate planer, the tool moves while the work is at rest. A suitable mechanism causes the rám A to move to and fro. When moving toward the left, the tool is cutting. As in the ordinary planer, the cutting speed is less than the return.

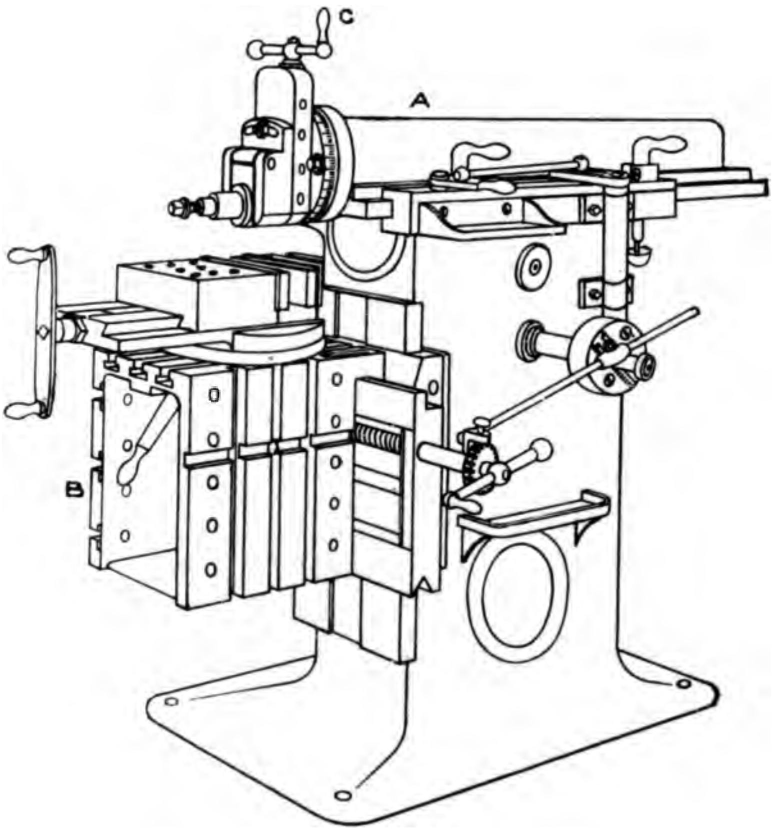


Fig. 180.

The work is held on the table B, which may be adjusted to any convenient height suited to the work to be done. The tool is also allowed a limited vertical adjustment in the slide by turning the handle C. This is the ordinary method of obtaining the vertical feed.

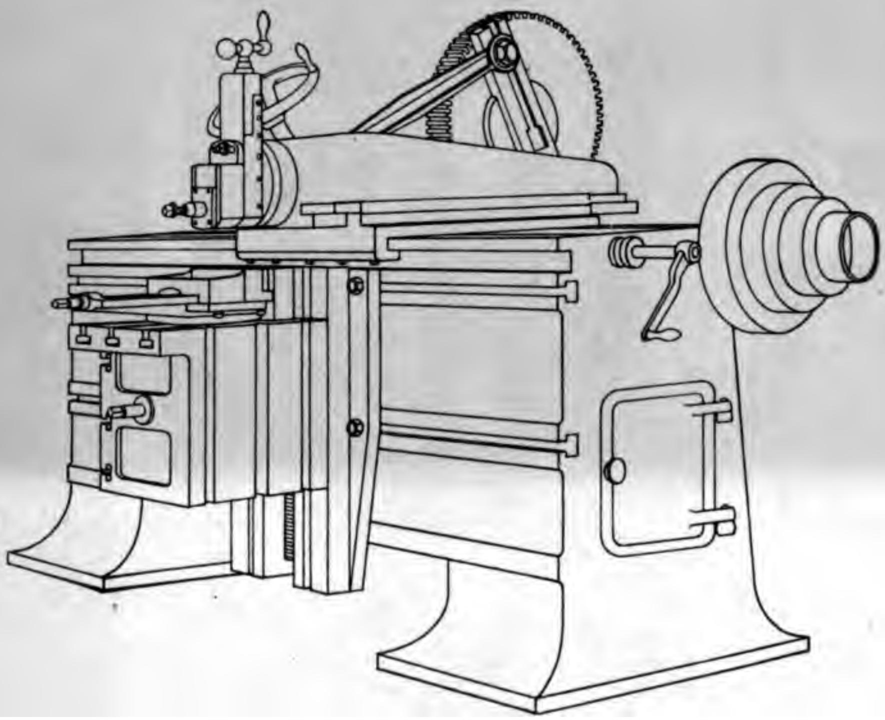


Fig. 181.

The horizontal feed is obtained by moving the table B sidewise. In some shapers it can also be moved vertically to feed to or from the tool; in others the horizontal feed is obtained by causing the tool with the reciprocating parts to move sidewise.

The style of machine shown at Fig. 180 is called the pillar shaper, but where the tool and ram move sidewise it is called the traverse shaper; see Fig. 181. The character of the work done on the shaper and the planer is identical, but as a rule, the shaper is used for the smaller and more delicate parts which could not be handled quickly on the planer. The shaper has the additional advantage of a change of speed which allows small pieces, especially of the softer metals, to be machined at a maximum rate.

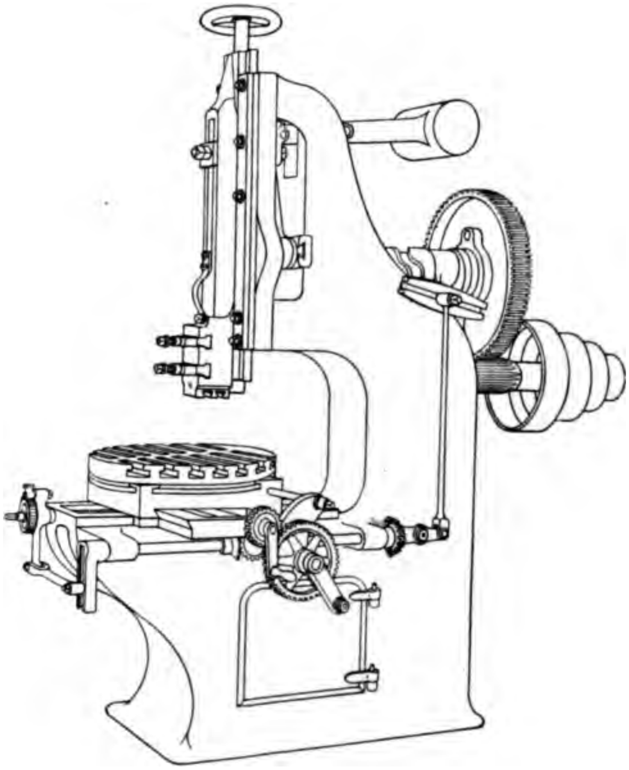


Fig. 182.

Slotter. Another machine tool which is not used as commonly as its many good qualities would seem to warrant is the slotter, Fig. 182. It is, in reality, a shaper with the tool moving vertically instead of horizontally. It is used for working on heavy pieces, and especially in places where an irregular contour is to be formed. The thrust on the tool is vertical, and it must be very stiff. The work done frequently partakes of the nature of the forming of the inside of the hole where the tool must project the whole length of the cut below the bottom of the head. Such a case is that of the slotting of locomotive frames. The best type of tool for such a class of work is a strong bar, as shown in Fig. 183. The bar is held in the head of the tool just as any tool would be. Near the lower end it carries the cutting tool, which may be fastened by a set-screw or wedge. Such a tool should always be used when it is possible. It has the advantage of being stiffer and less likely to spring than a forged tool.

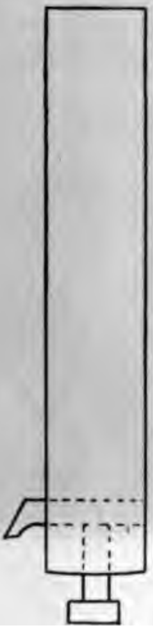


Fig. 183.

The tool used in a slotting machine differs from that used in the lathe or planer in that the direction of the cutting motion is different. Fig. 184 illustrates a slotting tool to be used for doing such work as the cutting of keyways in the hubs of pulleys. It will be seen that if the tool is moved in the direction of the arrow, the face B becomes the one against which the chip bears. It, therefore, corresponds to the top of the lathe tool. The sharper the slope given to the face B, the keener the edge, just as increasing the rake of the lathe tool increases its sharpness. The face A must also be cut away as indicated. This corresponds to the clearance of the lathe or planer tool. It is quite possible, at times, to give these tools a larger amount of rake. Such a form

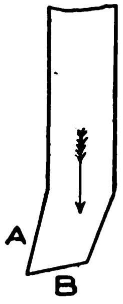


Fig. 184.

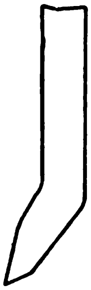
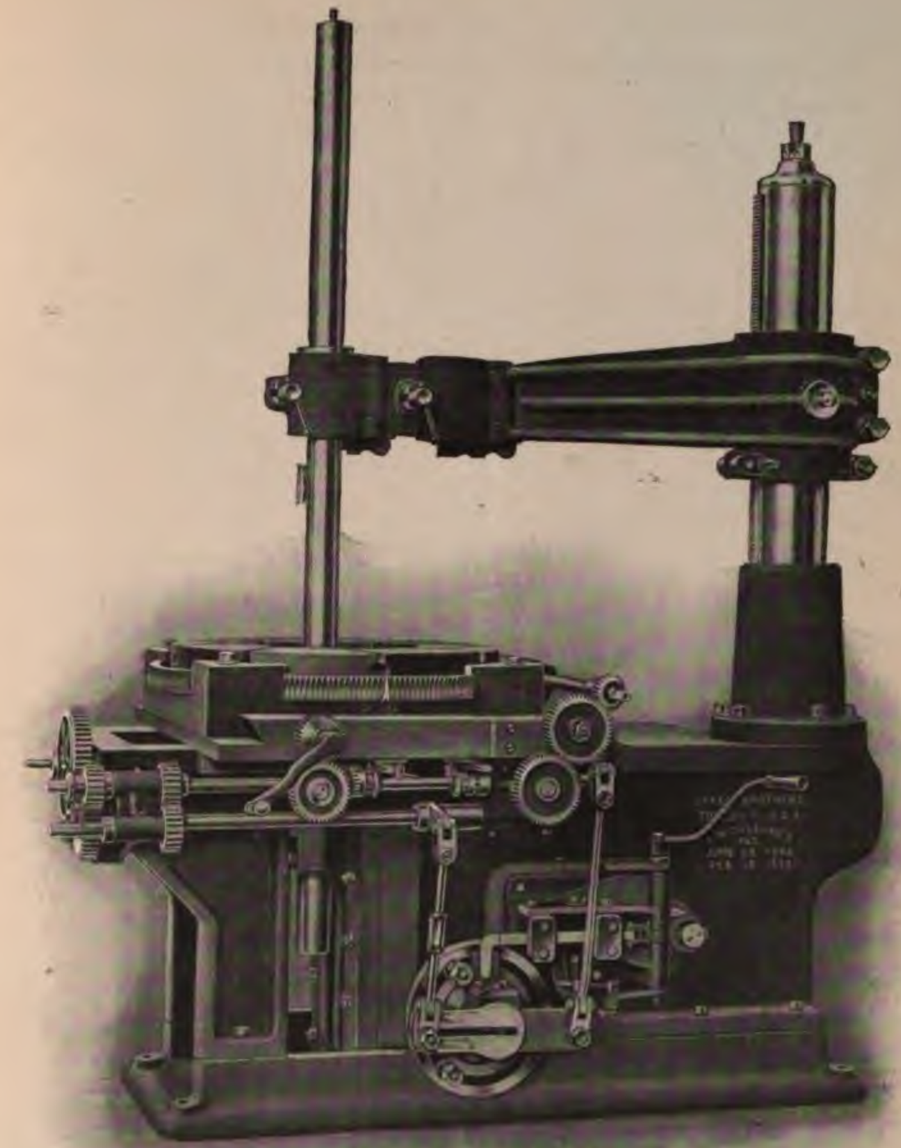
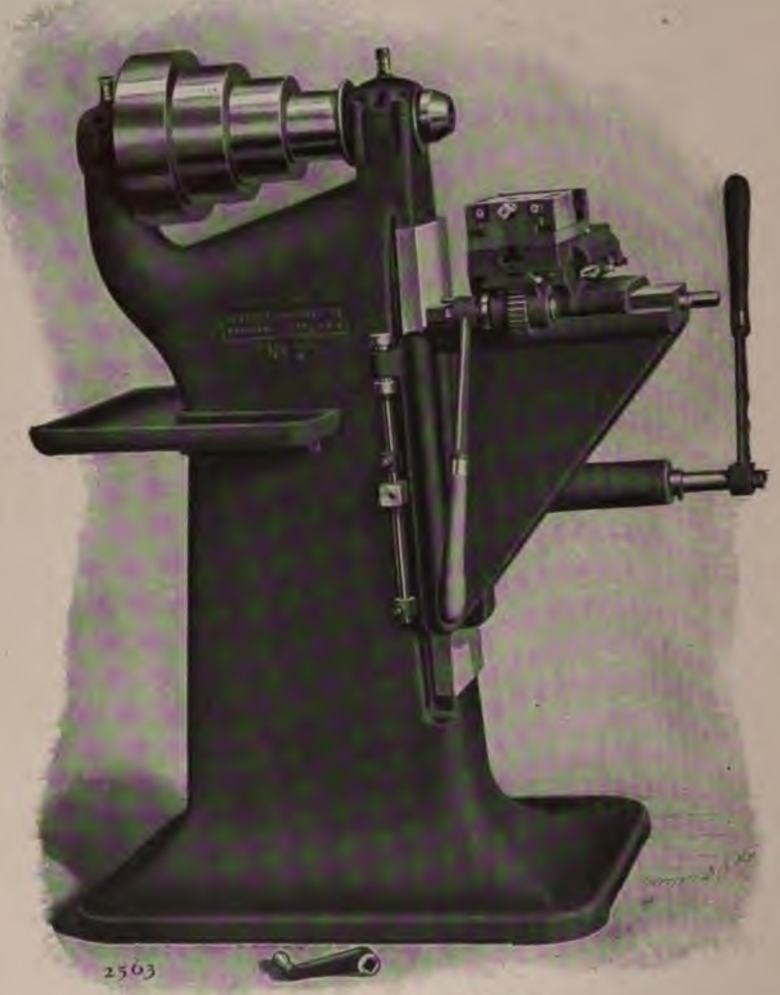


Fig. 185.



DRAW STROKE SLOTTER.
Baker Brothers.

is shown in Fig. 185. The shape of this tool is such that it is very strong in the direction of the thrust, besides having a keen cutting edge.



HAND MILLING MACHINE.
Pratt and Whitney Co.

MACHINE SHOP WORK.

PART III.

THE MILLING MACHINE.

The operation known as milling differs so radically from the removal of metal by methods previously described, that it merits much more careful and lengthy discussion than has been devoted to the other methods. Due, also, to its increasing importance and general use, it calls for a somewhat extended discussion. While milling is coming rapidly into favor as a means of doing work which has formerly been done on the shaper and planer, it does not follow that the shaper and planer are to be entirely abandoned. There has been a tendency during the past few years to belittle the planer and shaper in favor of the milling machine. This tendency is not warranted even by the rapid and economical method of milling. There is a large class of work which can be done accurately only by means of a single-pointed tool such as is used in the planer and shaper.

The fundamental difference between planing and milling lies in the character of the tool employed. The planer uses a fixed single-pointed tool with a reciprocating motion either of the tool or the work, while milling is performed by the use of a rotary tool with several cutting points, of which the circular saw is a familiar example. This rotary multiple cutter is the basis of all milling operations, and, as the saw may be taken as a good example of such a cutter, so the work done by the circular saw in cutting metal may be said to be an example of milling. The ordinary milling cutter is nothing more than a saw in which the contour of the cutting blades is made to suit the work in hand.

Circular saws for use upon metal have been, and still are, often mounted in a hand lathe, Fig. 186. The saw is held on an arbor between centers, and the work placed on a table rest, which takes the place of the T-rest used in ordinary hand turning. Here is an example of milling in its most primitive form; the work being fed to the saw by hand, with no guides or positive movements. It was an easy matter to provide guides on the table rest for the work, and the next real important step was to use an engine lathe in place of the hand lathe. Here the saw was mounted as before, the work clamped to the carriage by suitable fixtures and fed positively to the saw, both as to direction and amount.

It was but a step to make a saw wide enough to cover a considerable surface, or to have a thick saw with a suitably formed cutting edge. Several saws of different shapes and sizes can be mounted in a gang on an arbor and perform operations which it would be hard to duplicate on the shaper or planer. Even in the present age of special machines for milling, a great deal of work of this character is still performed in the engine lathe by the method indicated.

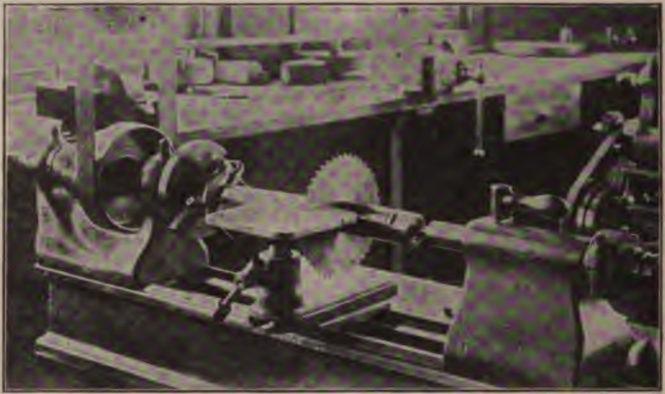


Fig. 186.

It is evident that one of the great advantages of milling is the certainty of exact duplication, a feature of prime importance in the manufacture of interchangeable work.

Of course, it was not to be expected that such an important operation as milling could be intrusted to a machine like the lathe, which was primarily intended for an entirely different, but equally important, class of work.

About the first machine built exclusively for milling was the so-called Lincoln miller, Fig. 187, which consists essentially of a bed carrying the equivalent of the head stock and tail stock of a lathe, with means for rotating the cutter arbor, which is carried directly by the head stock spindle, and steadied and supported by the tail stock. There is also provided a table upon which the work can be fastened either directly, or by means of a vise, and an automatic feed across the machine at right angles to, and below, the cutter arbor. This is simply the milling attachment in the lathe transferred to a machine designed to do nothing but milling.

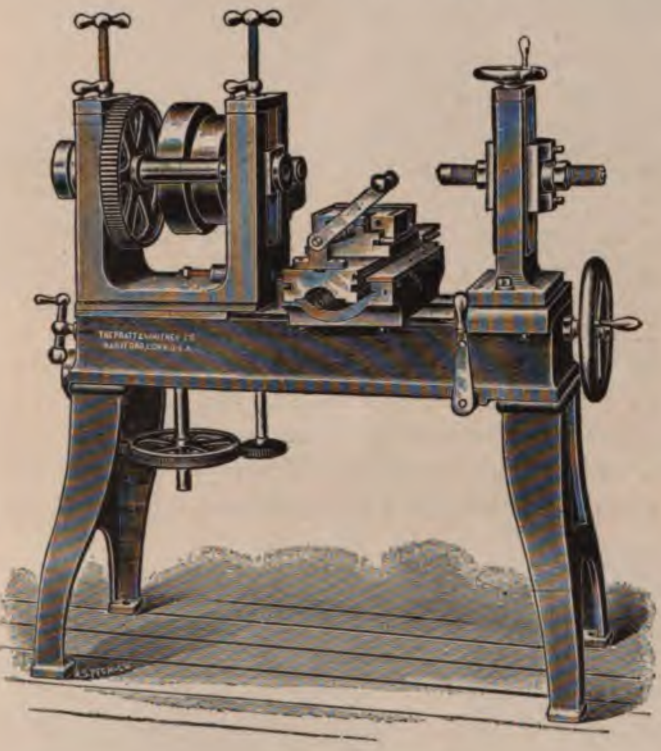


Fig. 187.

The elementary cutters designed to be used on this type of machine are of the form already described, viz.: of the saw type.

As the **types of cutters** used determines, in a large measure, the design of the machines themselves, it will be better at this point to take up a description of some of the different cutters, in order that the adaptation of the machine to the cutter may be clearly seen.

Screw slotting cutters, Fig. 188, and slitting saws, Fig. 189, are indentical with the saws which, we have already seen, were employed in the lathe. The true milling cutter, Fig. 190, has a face much wider in proportion to its diameter than the common saw. It is for the production of surfaces, rather than for a thin saw kerf for separating pieces of metal. These plain cutters are made in a large number of diameters and lengths, and are all designed for the generation of plane-surfaces.

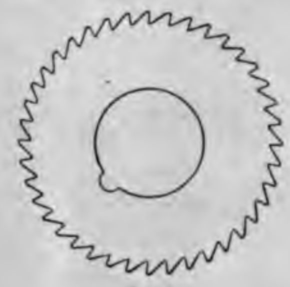


Fig. 188.

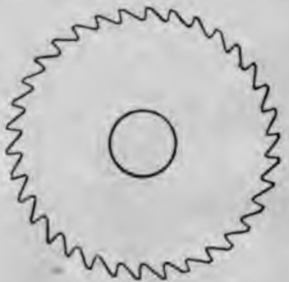


Fig. 189.

As we have seen in the case of reamers, heavy cuts can be taken more easily when the chip is broken up into small pieces, therefore in milling cutters designed for roughing, it is customary to nick the teeth, see Fig. 191, in such a way that the space left by one tooth may be taken out by the following tooth. This makes the cutting easier. A plain cutter of any considerable length will not make a smooth surface because of the varying pressure of the cutter, as one tooth after another leaves the work. To avoid this springing tendency, cutters are made with **spiral teeth,** Fig. 192,

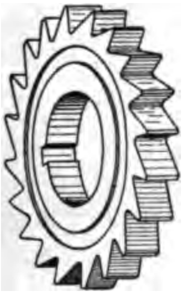


Fig. 190.

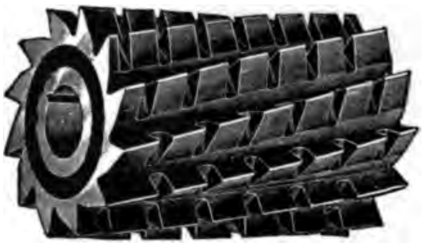


Fig. 191.

either right or left hand, so that there is practically a uniform distribution of pressure at all points during the cut.

When it is desired to mill the side of a piece, it is necessary that there should be teeth on the side of the cutter. Such cutters are usually made comparatively narrow and with teeth on both sides, as shown in Fig. 193. These **side milling cutters** are usually sold in pairs, as they can be mounted together and thus mill off both sides of a piece of work, similar to a bolt head, and are, therefore, called heading or straddle mills.

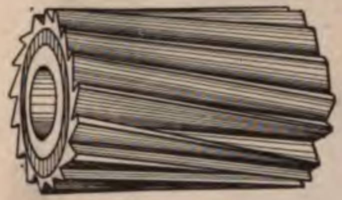


Fig. 192.

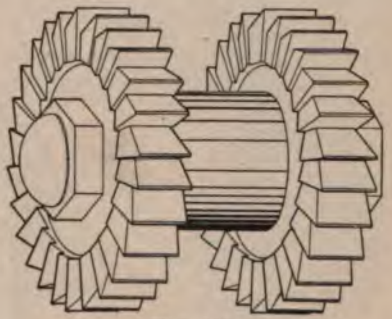


Fig. 193.

If two cutters of the same diameter are mounted together, it is difficult to mill a surface which will not show the point of separation of the cutters. This can be avoided by making the ends of the cutters, where they come together, of such a shape that they interlock one with the other. This feature of interlocking, see Fig. 194, is especially valuable when cutting slots which must be of a definite width. An ordinary cutter will wear away by use, or by grinding, and thus lose its correct size. The thickness of interlocking cutters can be maintained by means of very thin washers, and, due to the interlocking of the cutters, will not show that any space exists between them.

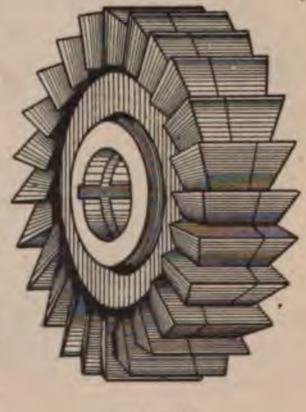


Fig. 194.

Cutters may be mounted in **gangs** of great variety and combination, a typical one being shown in Fig. 195. These cutters may be of any desired form, and can be made to produce a variety of shapes. The so-called angle cutters, Fig. 196, are employed in the manufacture of cutters, and, when making spiral cutters, must have an angle on both sides. The customary angle in such cases being 40° on one side and 12° on the other. The other common single angle cutters vary from 40° to 80°, either right or left hand. Double angle cutters can be had with either 45°, 60°, or 90°, included angle.

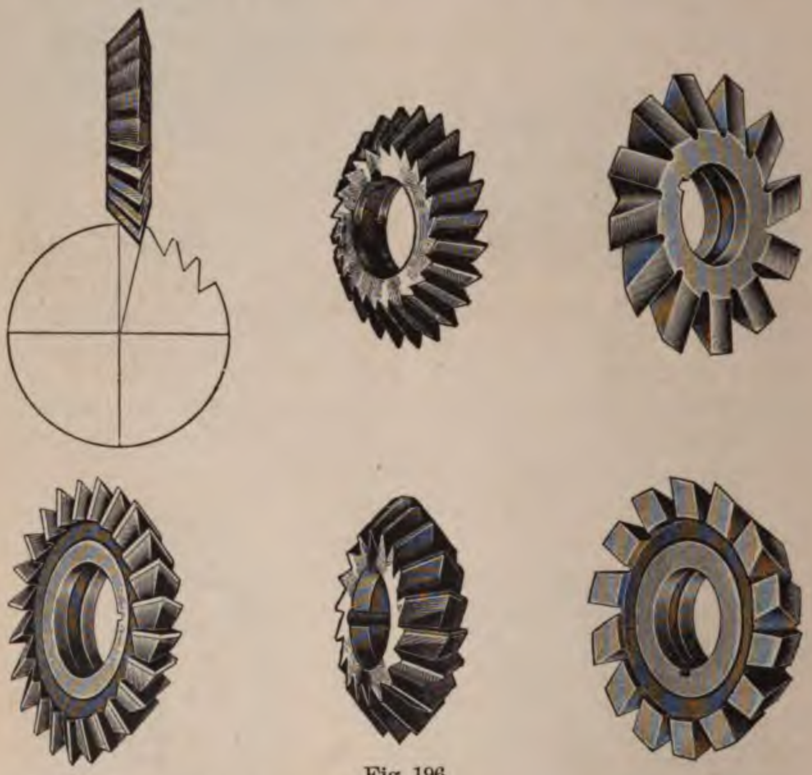


Fig. 196

We have considered up to the present time, only such cutters as are made from a single piece of steel. In large cutters, however, the cost of the steel becomes an important item, and there is danger of losing a large amount of labor through accidents in hardening. To make a cheap serviceable cutter of large size, it is customary to use a cast-iron body with inserted steel teeth. There are several different methods of holding these teeth. Usually, when the inserted tooth is in the form of a blade, they are held by taper pins or screws, Fig. 197. These blades are renewable, the cast-iron body being used many times. A cheaper, permanent cutter can be made by casting the body around the teeth, thus making a very rigid support for the blades.

Another form of **inserted-tooth cutter** consists of round hardened steel pins driven into holes in a cast-iron body. This cutter is also permanent in form, Fig. 198, as broken teeth cannot be replaced, and, when the teeth are worn almost down to the body, the whole cutter is thrown away.

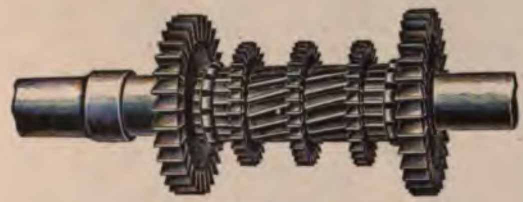


Fig. 195.

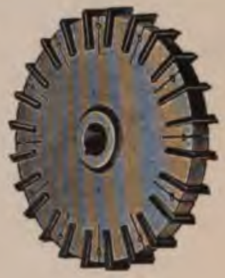


Fig. 197.

Brief mention has been made of cutters to generate irregular contours. These cutters are known as **formed cutters,** and, except in certain shapes, such as quarter and half rounds, are not carried in stock, but are made only to order. There is such a large variety of forms for which such cutters may be used, that it is impossible to give more than a typical example. The form shown, Fig. 199, consists in reality of several cutters, some of them of ordinary

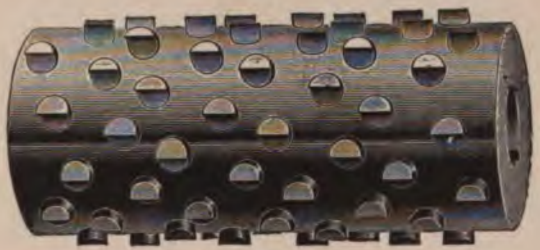
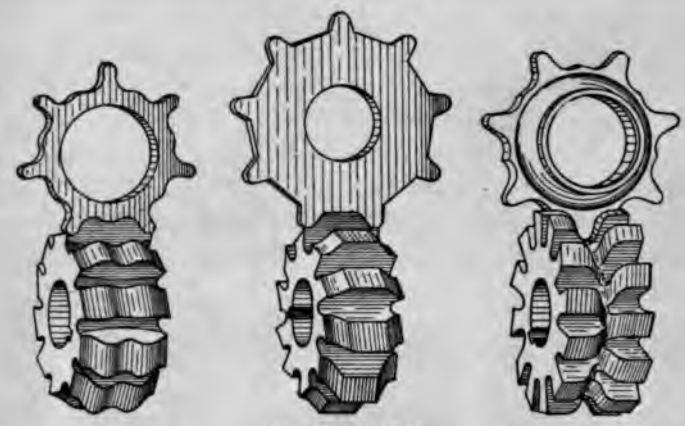
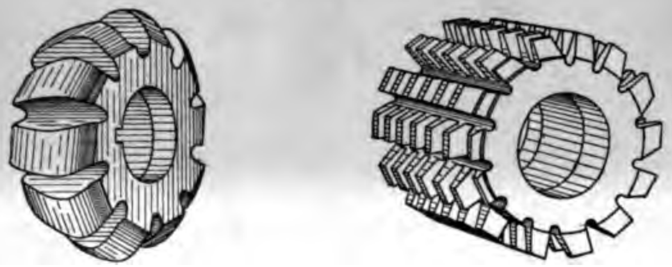


Fig. 198.

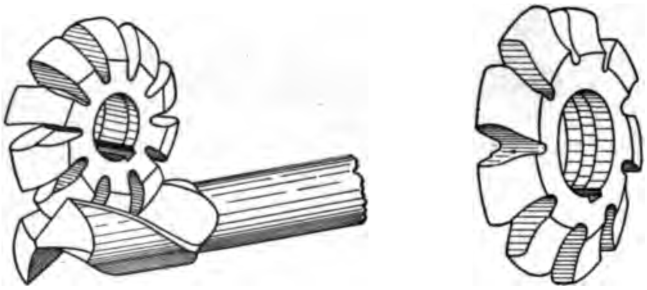


Sprocket Cutters.



Tap and Reamer Cutter.

Worm Gear Hob.



Twist Drill Cutter.

Gear Tooth Cutter.

Fig. 200.

shapes and sizes, with others of special forms, the whole making a gang cutter whose object is very apparent.

Among the standard shapes of formed cutters are some which are now carried in stock for producing certain tools which require cutters of definite yet peculiar form. Among these may be mentioned cutters for fluting taps, reamers, and twist drills, cutters for sprocket and gear teeth, and cutters, known as hobs, for the production of worm gears. See Fig. 200.

End Mills. All the cutters thus far mentioned are provided with central holes, and are intended to be mounted on an arbor which is carried by the spindle and supported in some suitable manner at the outboard end. There is an entirely different class of cutters, however, which are supported by the spindle only, and are provided with teeth on the end of the cutter. These are known as end mills. They are made in a great variety of shapes and sizes, the ordinary end mill, Fig. 201, being cylindrical, with either a right or left-hand spiral.

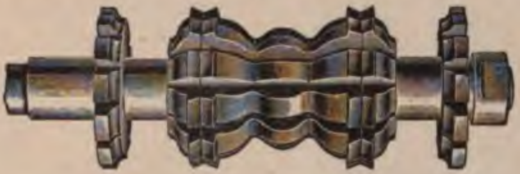


Fig. 199.

A special form of end mill for making T-slots is called the T-slot cutter, and is, in reality, a small side milling cutter carried by a small central stud, see Fig. 202. Dovetail cutters, and cutters of various angles for making ratchets, are merely variations of the end mill.

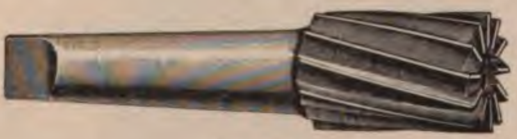


Fig. 201.

When end mills are made of large size, they can be furnished with inserted teeth similar to those used on cutters for the arbor. See Fig. 203. The heaviest end mills for the milling machine are sometimes made as large as fifteen to twenty inches in diameter, the cast-iron body being screwed directly on the nose of the spindle, making a very powerful and fast-cutting tool.

The plain milling cutter is mounted on an arbor in a way very similar to that in which its prototype, the circular saw, was mounted. For use in the lathe, this is usually centered at both ends and driven by a dog. When used in a regular milling machine, the arbor, Fig. 204, is fitted with a heavy taper shank

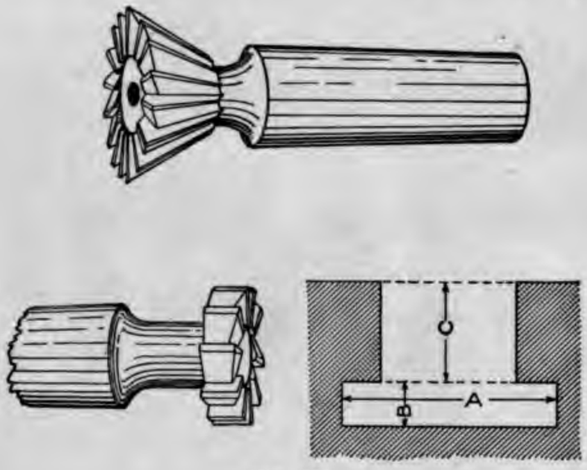


Fig. 202.

with a tongue at the end for driving, and washers of varying thickness, so that cutters of different widths may be used on the arbor, and, to suit the position of the work, in different positions on the same arbor. The washers and the cutter must have absolutely parallel faces. Otherwise, when the nut at the end of the arbor is tightened, there will be springing of the arbor due to the irregularity in thickness. The outboard end of the arbor is provided with a center or straight pin to be steadied by the over-

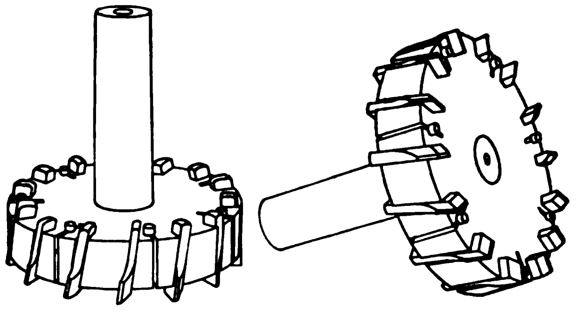


Fig. 203.

hanging arm, and the nut on the arbor should not be tightened until this arm is in position, as there is danger of springing the arbor by the leverage of the wrench.

Where the cutter teeth are formed integral with, or fastened to, the taper shank, as in the case of end mills, the shank, if it be of a proper size, is forced directly into the taper hole in the spindle. In many cases, however, the taper shank of the cutter is much too small to fit the spindle hole, and taper collets, Fig. 205, are used to bush down the spindle hole to the proper size. Of course, it is necessary that the axes of the outer and inner tapers should coincide, otherwise the cutter will not run true. In some cases it is necessary to use two collets, one within the other, before introducing the cutter shank.

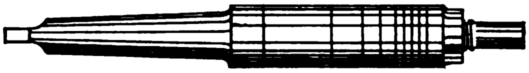


Fig. 204.

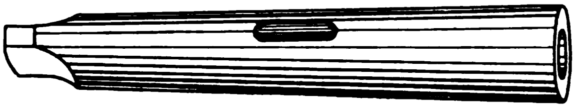


Fig. 205.

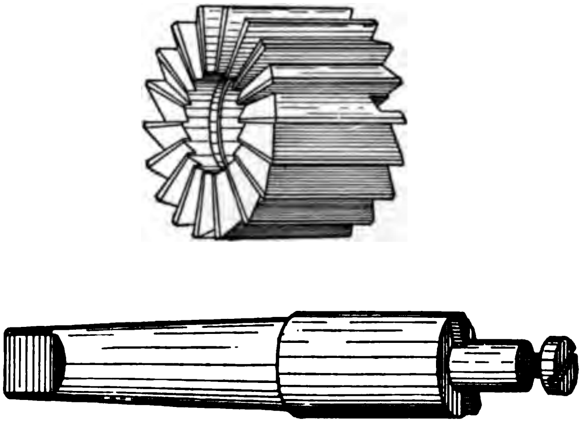


Fig. 206.

When **shell end mills**, Fig. 206, are used, a special form of taper shank is employed which can take several different sizes of cutters. The construction is so obvious from the illustration that explanation is unnecessary.

End mills, held on taper shanks, rely on the friction of the taper for holding in position, although being driven by a tongue at the end of the shank. Therefore, cutters of this description should not have a spiral in a direction which would tend to pull the cutter out. This is not a serious objection when using the cylindrical portion of the cutter, but, when using the end of the cutter, it means that the teeth can have no rake and must scrape, rather than cut the work. In order to use a leading spiral on the cutter, the shank must be held positively in the spindle. This usually is accomplished by inserting in a threaded hole at the rear end of the shank, a rod which extends through the hollow spindle and brings up against a collar on the outside. This can be set up solidly, and all danger of loosening up of the cutter shank will be avoided.

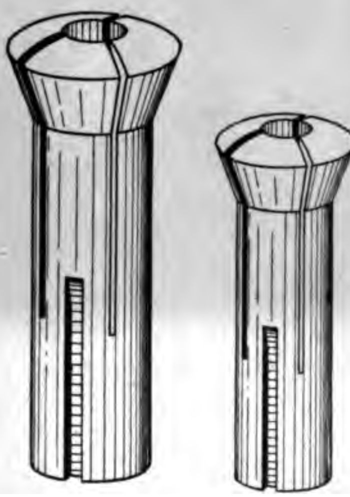


Fig. 208.

When the cutter is small, as compared with the diameter of the spindle taper, a screw collet may be used, as the friction of the collet will be greater than the tendency of the leading spiral to move the cutter from the spindle. Again, these screw collets are commonly made of machine steel, while the end mills are made from tool steel. The short, steep taper and threaded end are shorter than the long taper shank, and therefore make a cheaper cutter.

One of the best means for holding small end mills is by the use of spring collets, Fig. 207, which can firmly grasp the straight shank of the cutter. When cutters are to be changed frequently, this is a particularly satisfactory method, although it will not answer for roughing cuts with cutters of large diameter.

An ordinary drill chuck can be held in the spindle by means of a taper shank, and furnish a means of holding straight-shank drills and other small straight-shank tools.

A very convenient method of holding certain tools consists in fitting a three-jawed universal lathe chuck to the threaded nose of the spindle, thus enabling straight-shank tools of large size to be held firmly and accurately. Cutters of any kind are rarely held in chucks on the milling machine, but a large number of other small tools can be thus fastened to very great advantage.

In taking up the subject of machines devoted especially to milling, it is well to consider that the transition from milling in the lathe to the special milling machine, is bridged by an attachment to the lathe by which the functions of the milling machine were well served. This is especially noticeable in milling attachments attached to bench lathes, Fig. 208, said attachment being mounted on a foot connected with the end of the bed, and the head stock turned around on the bed to serve as a spindle for the milling attachment. This temporary arrangement, which is still used as a combination in some cases, led to the introduction of the **bench miller,** Fig. 209, which was naturally intended for small work only, and therefore is not provided with automatic feeds, hand feeding by means of levers being used.

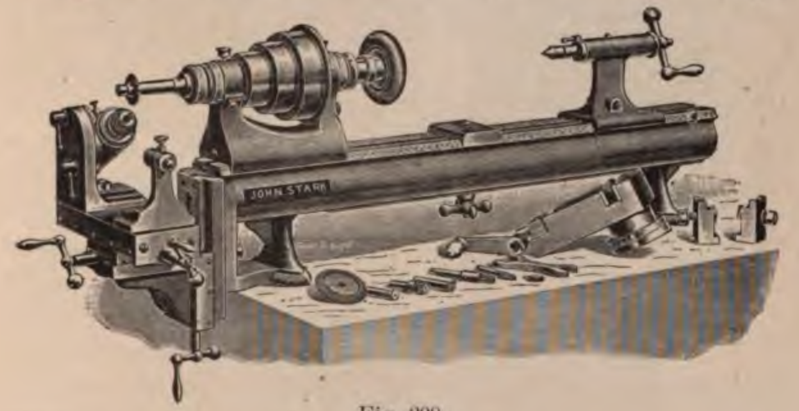


Fig. 208.

As this bench milling machine comprises all the essential elements of the more elaborate machines, it will be well to call attention to the principal parts of the machine and their functions.

The horizontal milling machine consists of a frame or box structure carrying a horrizontal spindle in the upper portion, together with brackets or an overhanging arm to steady the spindle. The front of the machine is carefully scraped at right angles to the spindle, and there is mounted thereon a knee, its upper surface being parallel to the spindle in the horizontal plane and capable of movement in a vertical direction. This knee carries what is known as the saddle, the upper portion of which is also parallel to the spindle. The movement of the saddle is towards and from the frame of the machine, and therefore parallel to the spindle. The saddle, in turn, carries the table to which the work is attached by means which will be described. The upper surface of the table is parallel to the spindle, and the table movement is at right angles to the spindle in the horizontal plane.

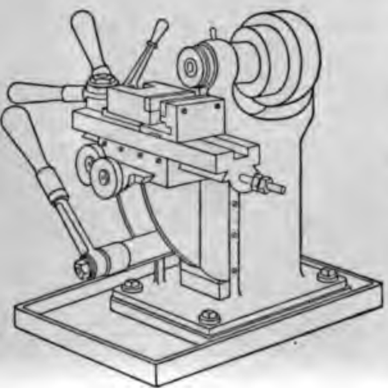


Fig. 209

The combination of these three motions, at right angles to the spindle in the vertical plane, parallel to the spindle in the horizontal plane, and at right-angles to the spindle in the horizontal plane, give to the milling machine what is known as its range. It allows any portion of the table to be brought under the cutter at any distance covered by the vertical feed.

Among the principal advantages of the milling machine, are the wide range of working capacity and the accuracy with which the table can be placed with relation to the cutter. This accuracy is obtained by means of graduated dials on the feed screws, which are read directly to .001 inch, and, by estimation, to .00025 inch. For many years the milling machine was the only tool which supplied these **micrometer graduations**, but they are now being applied to nearly every class of machine tool in which accurate adjustment is necessary. A very common method of graduation is by the use of a screw with a pitch of $\frac{1}{8}$ inch and 200 graduations on its dial. In some cases, a screw with a pitch of $\frac{1}{4}$ inch is used with 250 graduations, but it is always safe to assume that the single graduation on a milling machine means a movement of .001 inch.

Lost motion or backlash between the screw and its nut in any of these adjustments is the cause of frequent error and should never be neglected. Even in a machine in excellent condition, when the motion of the screw is reversed, it will turn through an angle giving the equivalent of about .005 inch movement of the part being fed along, but with no actual movement of the part. As an example, if, in moving the table from the column, the operator carries it .003 inch too far, it will not suffice to simply turn the dial back three graduations. The table should be brought back several hundredths of an inch, and then advanced to within .003 inch of its former position. In order to facilitate the quick and accurate

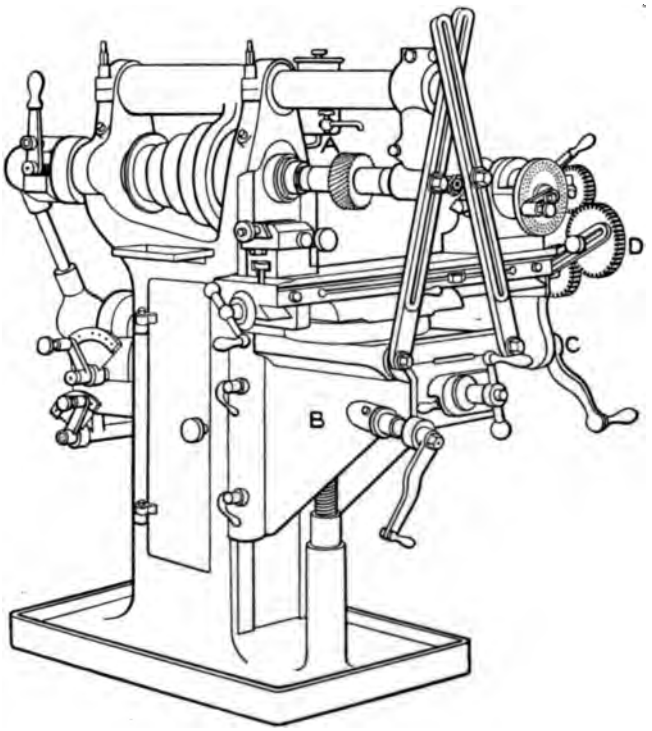


Fig. 210.

reading of these dials, they are arranged so that they can be readily set to zero whenever desired.

The movements above described for the adjustment of the work are those necessary for what is termed a plain milling machine. In order to have a **universal milling machine,** Fig. 210, it is necessary that the table be so arranged that it can be swung upon the saddle in the horizontal plane, so that its feeding movement is not at right angles to the axis of the spindle. Universal milling machines usually have a total angular movement of 90°, 45° on either side of the normal position.

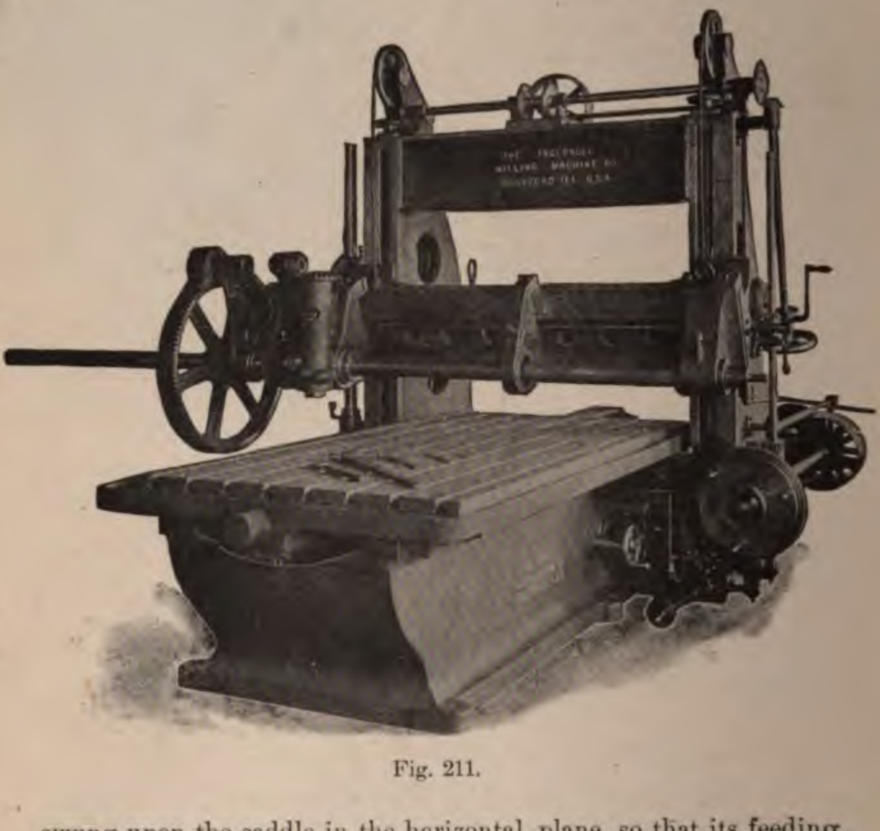
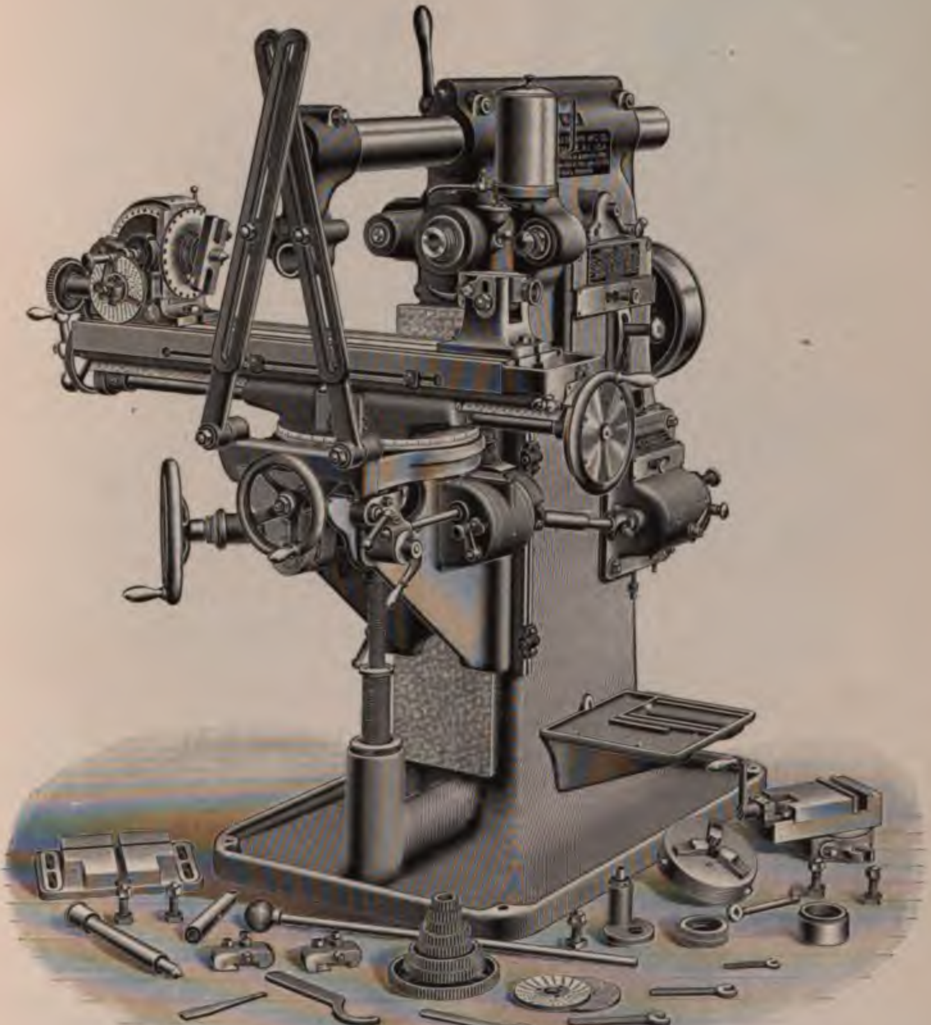


Fig. 211.

While the milling machine developed from the lathe through the Lincoln miller to the standard horizontal universal machine, its development, for work on which heavy cuts are necessary, took an opposite course.



UNIVERSAL MILLING MACHINE.
Brown and Sharpe Mfg. Co.

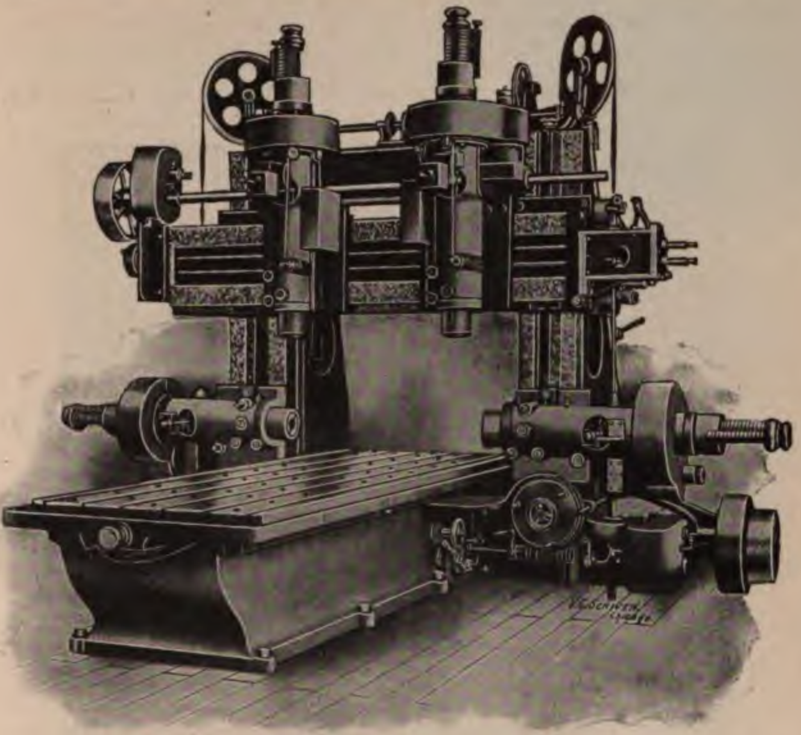


Fig. 212.

The slabbing miller, Fig. 211, is of the planer type, the cross rail carrying a rigidly supported cutter, while the table has the comparatively slow feed required for milling. This type of machine is especially valuable where broad surfaces are to be machined on pieces of work which are of such shape that they can be readily and uniformly supported to withstand the cut.

In order to produce true work by heavy milling, it is not only necessary that the work shall be supported as already outlined, but also, that the cut be nearly uniform in depth and width. If the section of the cut varies greatly, or, even with uniform cut, if the work is irregularly supported, the metal will spring under the influence of the cutter and it will be found that the work is not true. Therefore, work of a character that is liable to be distorted by the process of milling, may easily be performed to better advantage by the process of planing.

As the planer is sometimes furnished with more than one head, so these heavy milling machines are often furnished with more than one spindle. Two vertical heads on the rail and a facing head on each upright, Fig. 212, makes a machine capable of removing a large amount of metal, if the work is of such a character as to stand up under the cut.

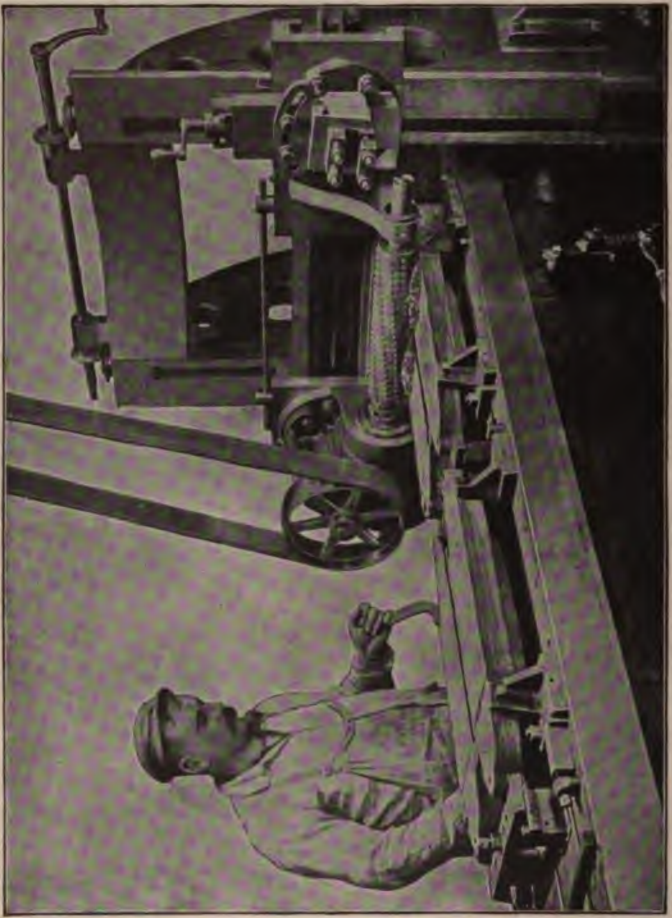


Fig. 213.

It is often desirable, from the point of view of economy of time, to combine the operations of milling and planing, and, with this end in view, milling attachments are made for the planer, Fig. 213, and attached to the cross rail. The changes required from the planer drive, are an extra belt to rotate the cutter and a special countershaft to slow down the movement of the table. This attachment can carry a slabbing, gang, or formed cutter on an arbor for horizontal milling, or it can carry end mills, Fig. 214, by turning the head through 90°, thus bringing the spindle to a vertical position. This last arrangement of the spindle is of great utility, as it allows cutters to reach down into places which would be inaccessible by any other means.

The advantages of the **vertical milling spindle** are so evident, that nearly all makers of horizontal machines furnish what is called a vertical head, Fig. 215. This vertical head is very rigidly supported on the column, and by means of the overhanging arm, so that cuts can be taken of as great depth as with the horizontal spindle. The vertical spindle can also be turned in the vertical plane, so that an end mill can be used at any angle with the table.

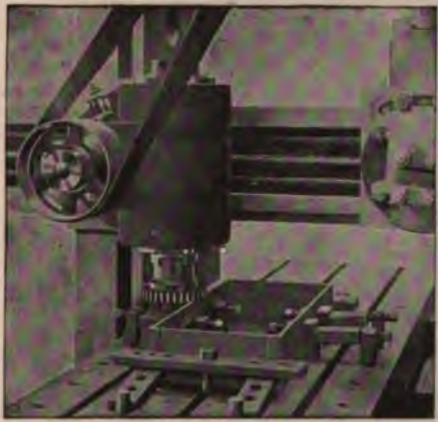


Fig. 214.

There are several machines made in which the vertical spindle alone is employed, Fig. 216, there being no provision for a horizontal spindle.

Such machines are provided with the feed motions of the horizontal type, and also with a rotating table by which circular work can be done. A large amount of work formerly done in lathes is now being done in vertical spindle machines, as well as many pieces formerly machined on planers and shapers.

The duplex milling machine, Fig. 217, has both the horizontal and vertical spindles combined in one, which allows the spindle to be placed at any angle from horizontal to vertical, and combines all the good points of both machines. The head of the duplex miller can be moved out over the table in such a way as to greatly increase the range of the machine, and this head is also provided with a drilling attachment whereby holes may be drilled at any angle. Attention is called to the rope drive on this machine by means of a twisted rawhide belt or rope. This makes a very smooth and quiet drive.

In order to accommodate different sizes of cutters, maintain a uniform cutting speed, and also to allow for difference in hardness of the material being worked, it is necessary that the milling machine should be supplied with several speeds. In the ordinary miller we usually have a four-step cone with back gears, which gives eight speeds with a single overhead belt. The countershafts for these machines are of the friction type, and are supplied with two driving pulleys in order that the machine may be driven in either direction. But, if the reverse motion is not desired, there can be two pulleys driving in the same direction, but at different speeds, giving a total, including the back gears, of sixteen speeds for each machine. The speed used on any particular work depends, as before stated, on the diameter of the cutter and the character of the work. Thus, with carbon steel cutters, the cutting speed will be 30 to 60 feet per minute. With high-speed steel cutters, nearly double these speeds may be maintained, if the drive of the machine is strong enough to pull the cut.

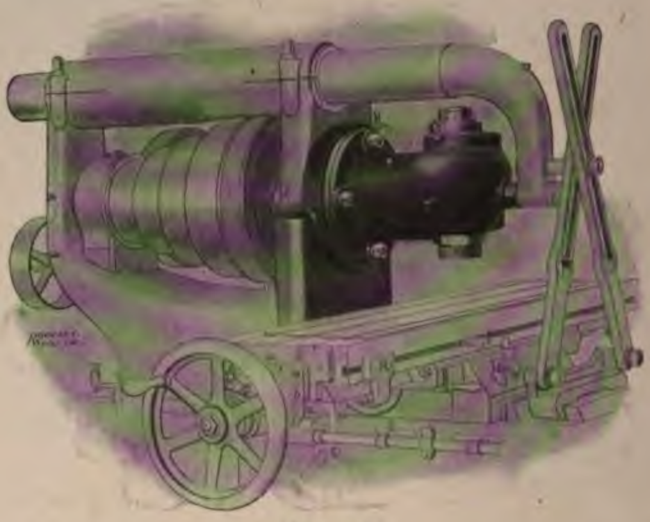


Fig. 215.

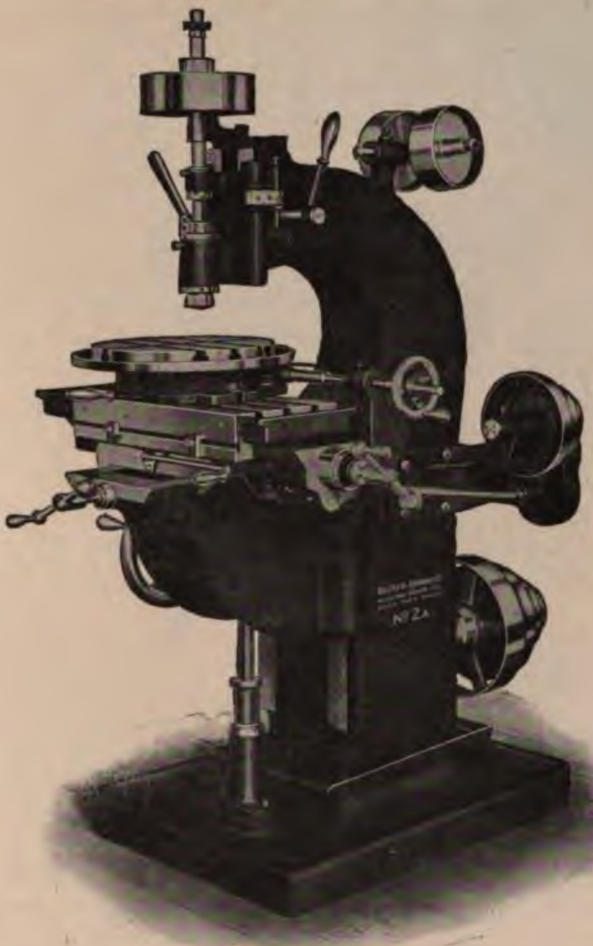


Fig. 216.

When using very small cutters, the machine itself will not give a speed which is high enough to suit the diameter of the cutter. For such work, a high-speed attachment, Fig. 218, is furnished, by which the small, light cutters may be driven at a suitable rate.

Of equal importance with the correct speed for the cutter, is the maximum feed or table speed, which is reckoned in inches per minute. A more logical method of designating the feeds, and one which has been adopted by several makers, is to give the advance of the table in thousandths of an inch for every turn of the spindle.

Based upon the use of the ordinary carbon steel cutters, The Brown & Sharpe Co. have prepared the following statements regarding the speed of mills: "It is impossible to give definite rules for the speed and feed of mills. The judgment of the foreman or man in charge of the machine should determine what is best in each instance.

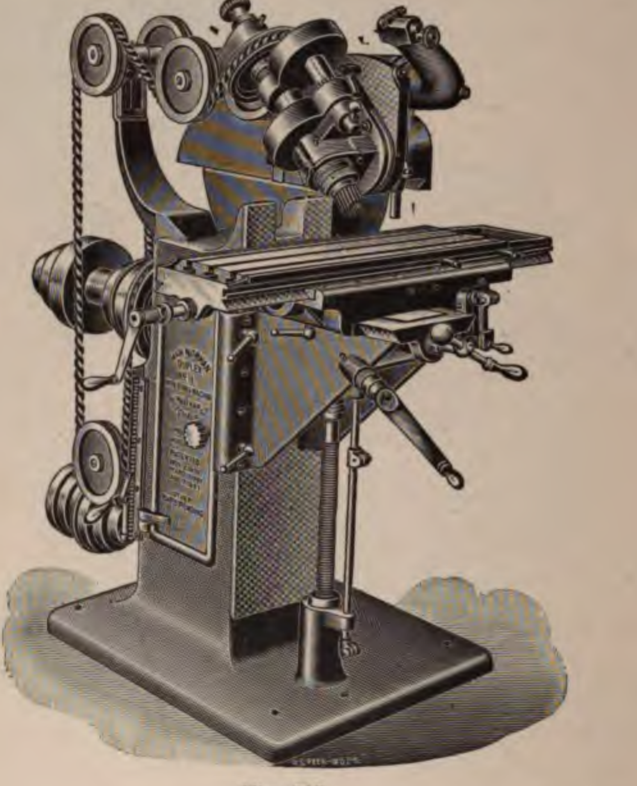


Fig. 217.

"As usually the highest possible speed and feed are desirable, it pays to increase them both until it is seen that something will break or burn, and then reduce to a speed and feed of safety. Sometimes the speed must be reduced, and yet the feed need not be changed.

"The average speed on wrought iron and annealed steel is, perhaps, 40 feet per minute, which gives about sixty turns per minute with mills 2½" in diameter. The feed of the work for this surface speed of the mill can be about 1½" per minute, and the depth of the cut about 1/16". In cast iron, a mill can have a surface speed of about 50 feet a minute, while the feed is 1½" per minute and the cut 3/16" deep. In tough brass, the speed may be 80 feet, the feed the same as in cast iron, and the chip 3/32".

"As small mills cut faster than large ones, an end mill, for example, ½" in diameter, can be run about 400 revolutions per minute with a feed of 4"."

Addy, an English authority, gives as a safe speed for cutters of 6" diameter and upwards:

Steel, 36 ft. per minute with a feed of ½" per minute.
Wrought Iron, 48 ft. per minute with a feed of 1" per minute.
Cast Iron, 60 ft. per minute with a feed of 1⅔" per minute.
Brass, 120 feet per minute with a feed of 2⅜" per minute.

He also gives a simple rule for obtaining the speed: The number of revolutions which the cutter should make when working on cast iron = 240 divided by the diameter in inches.

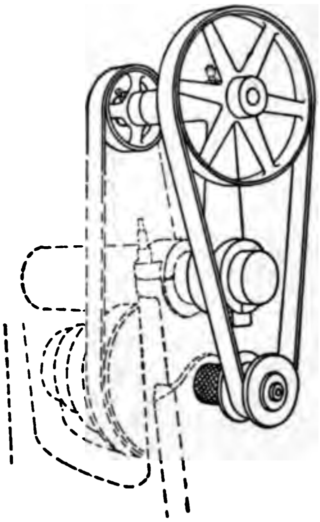
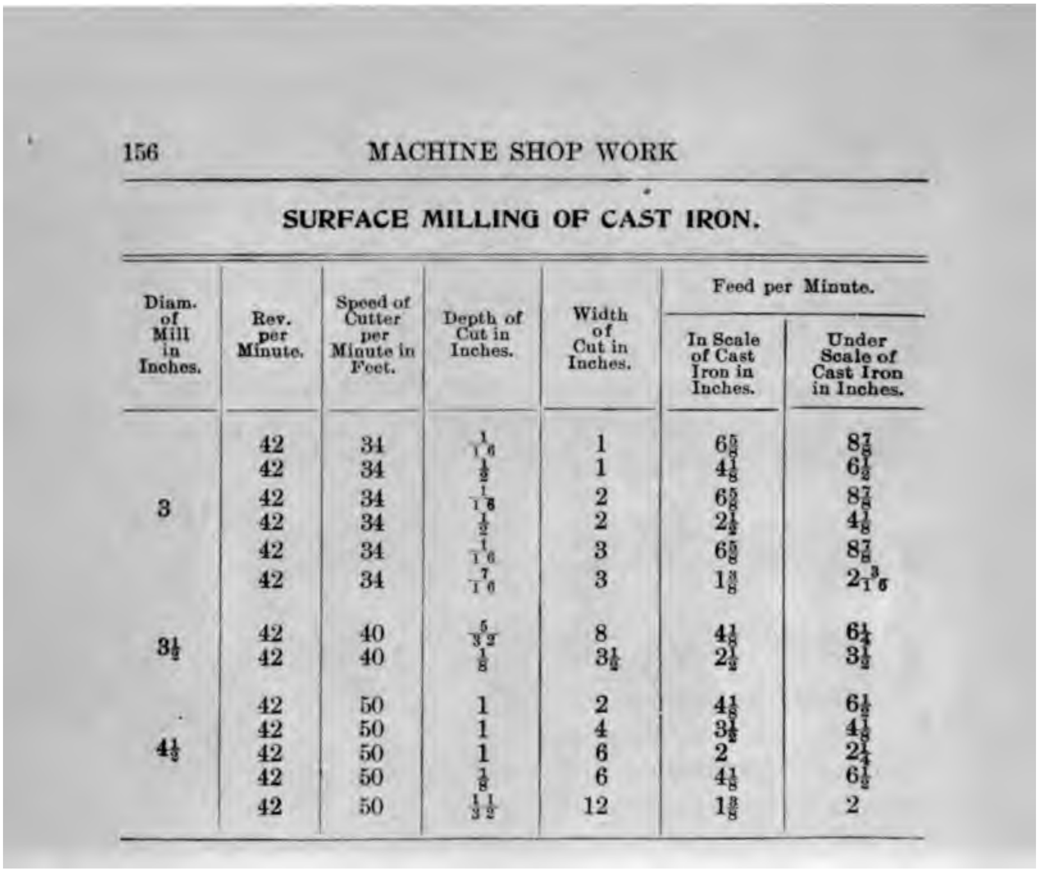


Fig. 218.

The following table has been prepared by Messrs. Brown and Sharpe to give the speed, feed, and depth of cut that can be obtained with a machine similar to that illustrated in Fig. 210.



SURFACE MILLING OF CAST IRON.

Diam. of Mill in Inches.	Rev. per Minute.	Speed of Cutter per Minute in Feet.	Depth of Cut in Inches.	Width of Cut in Inches.	Feed per Minute.	
					In Scale of Cast Iron in Inches.	Under Scale of Cast Iron in Inches.
3	42	34	1/16	1	6⅝	8⅞
	42	34	½	1	4⅛	6½
	42	34	1/16	2	6⅝	8⅞
	42	34	½	2	2½	4⅛
	42	34	1/16	3	6⅝	8⅞
	42	34	7/16	3	1⅜	2 3/16
3½	42	40	5/32	8	4⅛	6¼
	42	40	⅛	3½	2½	3½
4½	42	50	1	2	4⅛	6½
	42	50	1	4	3½	4⅛
	42	50	1	6	2	2¼
	42	50	⅛	6	4⅛	6½
	42	50	11/32	12	1⅜	2

SURFACE MILLING OF SOFT MACHINERY STEEL.

Diam. of Mill in Inches.	Rev. per Minute.	Speed of Cutter per Minute in Feet.	Depth of Cut in Inches.	Width of Cut in Inches.	Feed per Minute.	
					In Scale of S. M. S. in Inches.	Under Scale of S. M. S. in Inches.
3	38	30	1/16	1	6	8
	38	30	½	1	1⅛	1⅞
	38	30	1/16	2	2⅜	3½
	38	30	½	2	¾	1⅛
	38	30	1/16	3	1⅛	1⅞
	38	30	⅜	3	¾	1⅛
3½	38	35	1/16	8	1⅞	3
	38	35	⅛	8	¾	1⅛
4½	25	30	1/16	3	4	5
	25	30	1/16	5	2½	4½
	25	30	⅜	5		½
	25	30	1/16	10	1¾	2½
	25	30	3/16	10	½	⅞

END OR FACE MILLING OF CAST IRON.

Diam. of Mill in Inches.	Rev. per Minute.	Speed of Cutter per Minute in Feet.	Depth of Cut in Inches.	Width of Cut in Inches.	Feed per Minute.	
					In Scale of Cast Iron in Inches.	Under Scale of Cast Iron in Inches.
½	382	50	1/16	½	23	35
	382	50	⅛	½	7	11
1	191	50	1/16	1	30	40
	191	50	½	1	3	5½
1¾	109	50	⅛	1¾	17	23
	109	50	¾	1¾	3⅝	4⅛
5	42	55	¼	5	2⅝	4⅛
16	10	45	¼	16	⅞	1

FACE MILLING OF SOFT MACHINERY STEEL.

Diam. of Mill in Inches.	Rev. per Minute.	Speed of Cutter per Minute in Feet.	Depth of Cut in Inches.	Width of Cut in Inches.	Feed per Minute.	
					In Scale of S. M. S. in Inches.	Under Scale of S. M. S. in Inches.
½	267	35	1/16	½		
	267	35	¼	½		
1	152	40	1/16	1	3	4¾
	152	40	½	1		
1¾	87	40	1/16	1¾	2¾	4½
	87	40	¾	1¾		1¾

The milling machine, and in fact all the machines of the shop, can do efficient work only when they are well cared for. An important element is that they should be kept clean and well oiled.

Great care should be exercised that chips do not get into the holes in the spindles or between the arbor collars.

When at work, the milling cutter is kept flooded with oil or a solution of sal soda as already specified for lathe work.

Oil is used in milling to obtain smoother work, to make the mills last longer, and, where the nature of the work requires, to wash the chips from the work or from the teeth of the cutters. It is generally used in milling a large number of pieces of steel, wrought iron, malleable iron, or tough bronze. Frequently when only a few pieces are to be milled, it is not used, and some steel castings are milled without oil; also in cutting cast iron it is not used. For light, flat cuts it is put on with a brush, giving the work a thin covering like a varnish; for heavy cuts it should be led to the mill from the drip can that is usually sent with each machine, or it should be pumped upon or across the mill when cutting deep grooves, milling several grooves at one time, or, indeed, in milling any work where, if the chips should stick, they might catch between the teeth and sides of the grooves, and scratch or bend the work.

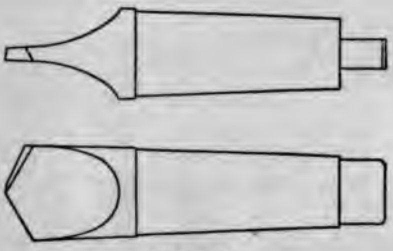


Fig. 219.

The Brown & Sharpe Co. recommend the use of lard oil in milling. Any animal or fish oil, however, may be used, and then separated from the chips by the use of a centrifugal separator, or by dumping into a tank of water. In the latter method, the chips fall to the bottom and the oil rises to the top, whence it may be drawn off with but little waste.

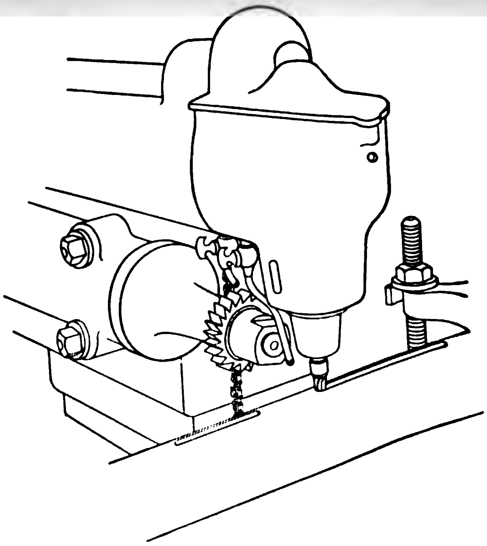


Fig. 220.

One of the operations for which the miller is particularly adapted is the laying out and drilling of holes which require to be accurately placed. The graduated feeds of the milling machine allow the distances to be set off as closely as .00025 inch, and holes can also be drilled to a given depth with equal accuracy. In starting holes, it is best to use a spotting drill, Fig. 219, which is extremely rigid and perfectly true. The spot made should be slightly greater in diameter than the drill to be used. The drill should be what is known as reamer size, that is, $\frac{1}{64}$ inch below the standard, and the hole may then be reamed, either in one operation, using a standard reamer, or by first using a machine reamer, which is about .005 inch under size, to be followed by the standard reamer. It is evident that holes thus drilled and reamed will be parallel, and, by using the vertical head, holes can be drilled at right angles in like manner. When extreme accuracy in holes is demanded, a boring bar may be used after the drill in order to correct any error due to the running of the drill itself.

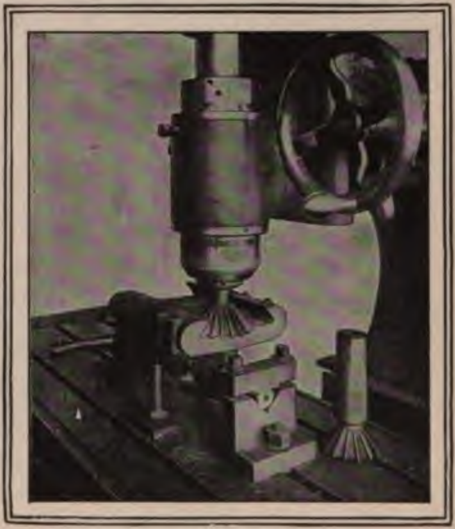


Fig. 221.

Splining Shafts. Another operation suited to the milling machine, although sometimes performed on the shaper or planer, is that of splining shafts. The slots in the table give the proper alignment to the shaft, the cutter can be set with correct relation to the axis without difficulty, and the spline cut full depth at one operation. The only objection to this form of spline is the curve at the end due to the shape of the cutter. An end mill in the vertical head can be used to remove this objectionable feature, and some splining machines are made, Fig. 220, which permanently carry both cutters, so that the work can be quickly shifted from one to the other.

The operation of making dovetails, which is a delicate and expensive job on the shaper, is readily performed on the milling

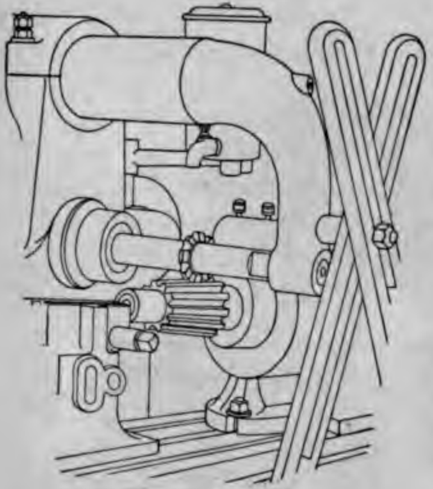


Fig. 222.

machine, especially of the vertical type, Fig. 221, the cutter being a form of end mill suited to the size and angle of the dovetail. T-slots are cut in a similar manner, either directly from the solid, or by following a groove made with a plain cutter.

One of the most common operations performed between centers is the fluting of taps and reamers, Fig. 222, which is done by the special cutters already referred to. It will be noticed that the cutter should be set in such a way that the cutting edge of the tap or reamer will be radial. If left as an obtuse angle, the tool will simply scrape and not cut, while if the tooth is undercut to any extent, it will be so weakened as to be liable to break.

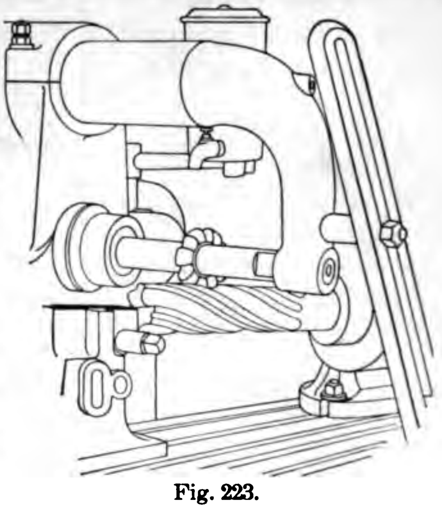


Fig. 223.

The flutes in twist drills and in spiral fluted reamers are also cut between centers, but, if the cutter is carried directly by the spindle, the operation requires a universal machine. If the cutter be carried by a vertical or sub-head of any kind, a plain machine will answer for the purpose. The angle to which the table or vertical head must be set for spiral cutting, Figs. 223 and 224, is the angle between the axis and the development of the spiral. This angle can be closely determined by the following graphical method: construct a right-angled triangle, having a base equal to the axial distance represented by one full turn of the spiral and a perpendicular equal to the circumference of the work. For strict accuracy, this circumference should be taken at one-half the depth of the flute. Draw the hypothenuse of this triangle, and the angle between the base and the hypothenuse may be closely determined by the use of a protractor, and will be the angle to which the table or head must be set. This angle can be more closely and quickly determined by a very simple problem in plane trigonometry, viz.:

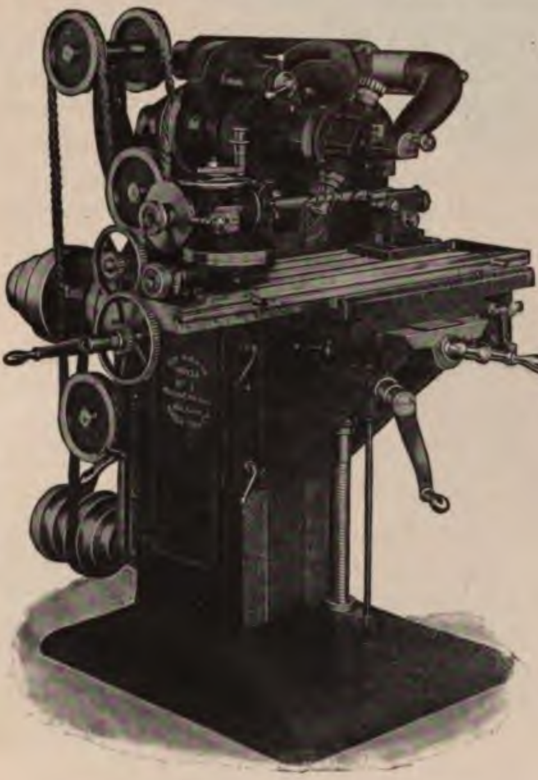


Fig. 224.

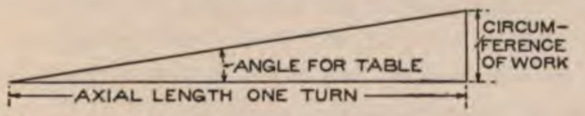


Fig. 225.

finding the sine of the angle. To do this, divide the perpendicular of this triangle by its base, and obtain the value of the angle from a table of sines.

Spirals. The cutting of spirals requires another operation different from ordinary work. In addition to the angular setting, the work must be rotated, in order to produce the spiral, as well as fed forward to the cutter. This rotation of the work must be positive, which means geared, and one rotation of the work will, of course, equal the pitch of the spiral, which is usually expressed as one turn in "n" inches. After cutting one spiral groove, the work is turned and indexed the same as in plain milling.

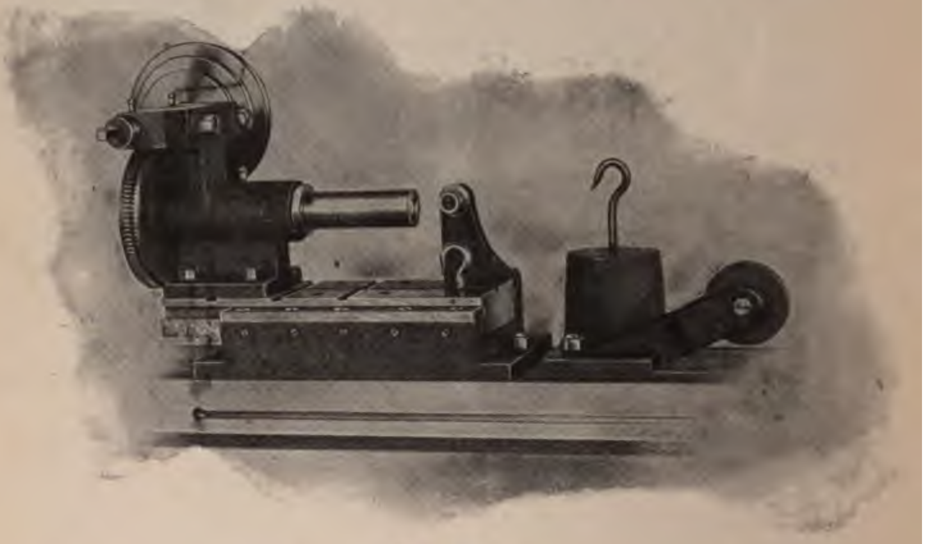


Fig. 266.

Cams. Both open and closed cams can be readily cut on a plain milling machine by the use of the cam-cutting attachment, Fig. 226, which nearly all makers are able to furnish. The outline of the cam is first laid out and worked down by hand on a plain disc, or male leader, as it is termed. This leader and a suitable blank are mounted, with their outlines coinciding, on the spindle of the cam-cutting attachment. A cam roll of the size to be used is mounted on a stationary roll stud, and an end mill of the same diameter, or enough larger for clearance, is mounted in the milling machine spindle directly opposite the cam roll. The spindle of the cam-cutting attachment is mounted on a carriage, which, by means of a weight over a pulley at the end of the milling machine table, is always kept with the leader in contact with the cam roll. A worm and worm gear are used for rotating the attachment, and thus the spindle approaches or recedes from the cam roll according to the shape of the leader. When cutting closed cams, it is sometimes desirable to use the hand-made male leader as a form from which to make a closed or female leader. This female leader will surround the cam roll in such a way that, even if the weight should fail to act, no serious damage can be done to the blank. The cutting of face cams differs from the above description only in that the spindle of the attachment is at right angles to the spindle of the milling machine instead of parallel to it. The leader and cam roll are used in the same manner as before.

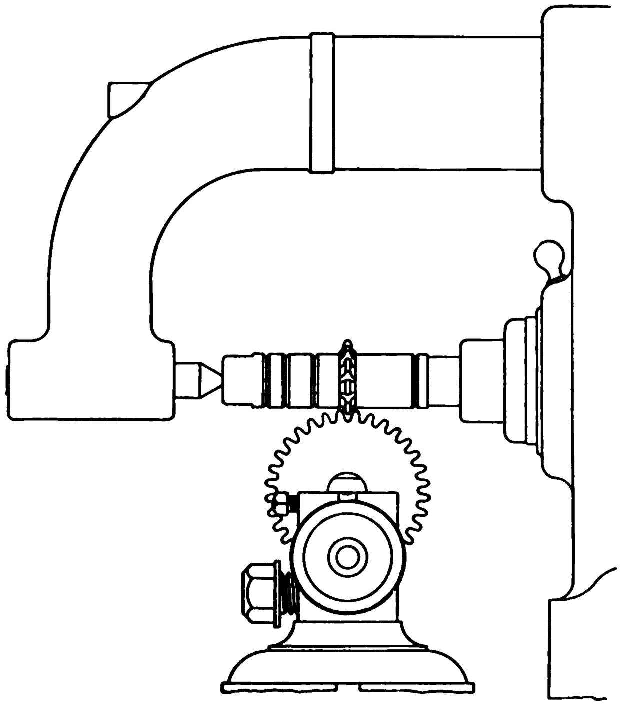


Fig. 227.

Gears. The cutting of gears of all descriptions was formerly done on some type of milling machine. although now each type of gear has its special, and, in many cases, automatic machine.

The cutters for spur and bevel gears are of two types, producing the cycloidal and involute tooth. For each pitch, the cycloidal system requires twenty-four cutters, while eight cutters suffice for the involute system. These cutters are plainly marked with the style of tooth, pitch, and number of teeth for which it is suitable. Some cutters are also marked with the whole depth of the tooth expressed in thousandths of an inch. The gear blanks, having been very carefully turned as to outside diameter, are mounted on an arbor between centers, and the cutter placed so that its central plane passes through, and is parallel to, the axis of the arbor. The knee is now raised until the cutter, when rotating, just touches the outside of the blank. The work is now moved out from under the cutter, and the knee raised, using the graduated dial, an amount equal to the whole depth of the gear tooth.

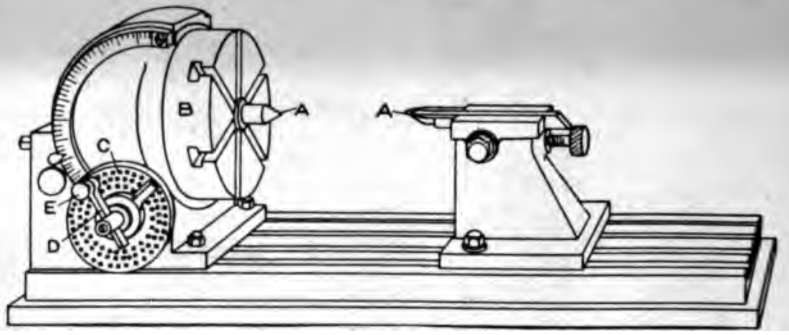
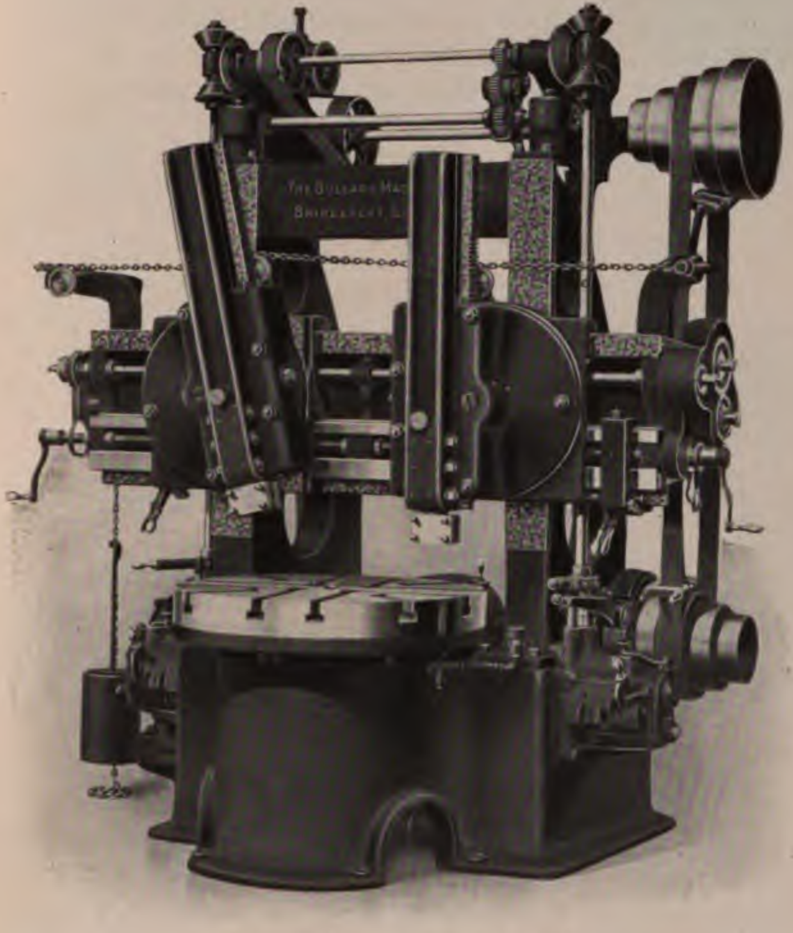


Fig. 228.

With the exception of the indexing, the gear is now ready to be cut, Fig. 227.

In order that the gear may be accurately and quickly set for each tooth, a dividing head is used, which is shown in Fig. 228. The mandrel upon which the gear is mounted is hung upon the centers AA, and firmly fastened to the spider B. The index plate C is geared to the spindle that carries the spider B; the index plate is drilled with a large number of holes. These holes are arranged in circles, and are accurately spaced at equal distances



42-INCH RAPID PRODUCTION MILL.
The Bullard Machine Tool Co.

apart. The arm D carries a stem E, having a knurled head at one end and a pin at the other. The pin is held in one of the holes of the index plate by a spring. The arm D can be moved to any desired position, relatively to the index plate, and there fastened.

When a gear is to be cut, the arm D is moved so that the pin is opposite a row of holes the number of which is the same or a multiple of the number of teeth to be cut. Thus, suppose a gear with 45 teeth is to be made. The pin may be set opposite the circle of 90 holes. Assuming that the ratio of revolution between D and B be 40 to 1 ; $\frac{1}{45}$ of a revolution at B requires $\frac{40}{45}$ of a revolution at D. The pin E must, therefore, be moved $\frac{40}{45}$ of 90 holes, or 80 holes, for each tooth cut.

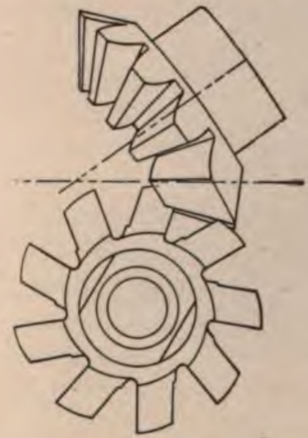


Fig. 229.

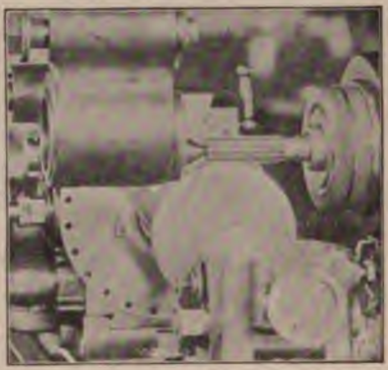


Fig. 230.

Bevel gears are held on an arbor in the dividing head, which is swung up to bring the bottom of the tooth parallel with the table, Fig. 229. As all parts of the tooth of a bevel gear are elements of a cone, it is evident that both the tooth and the space should vanish at the apex of the cone. No solid cutter, therefore, can do more than give an approximately correct shape to the tooth. Sometimes two cuts are made in order to more nearly approach perfection.

Spiral gears are cut in the same manner as any other spiral that is, by using the angular setting of the head or table together with positive rotation of the work.

Worm gears can be hobbed out by two different methods. The more common way is to gash the blank with a stocking cutter, then mount it on an arbor held loosely between centers so that the hob, when sunk into the gashes, will rotate the blank. The blank is raised slowly until the hob reaches the proper depth. A more accurate method is to positively rotate the blank at a speed corresponding to the pitch of the hob, and raise the rotating blank against the rotating hob until the proper depth is obtained. This method requires no preliminary gashing. See Fig. 230.

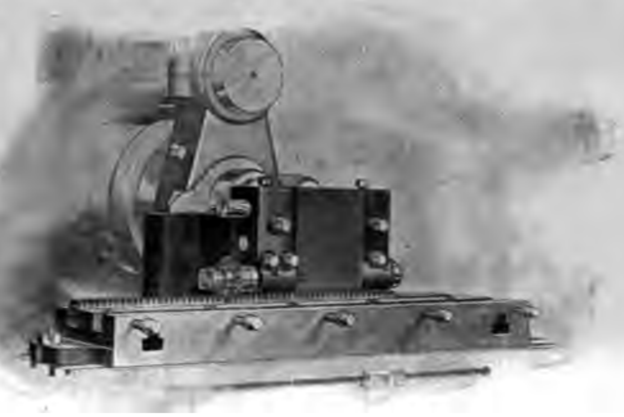


Fig. 231.

Rack cutting requires a special attachment, Fig. 231, so that the cutter spindle may be carried at right angles to the length of the table.

THE GRINDING MACHINE.

When greater accuracy than that obtainable on the milling machine or the lathe is required, recourse is had to grinding. The operation depends upon the abrasive or cutting qualities of emery, corundum and carborundum. With work properly held to a solid grinding wheel it is not difficult to attain great accuracy. By means of the grinding machine, parts may be economically finished even in hardened steel that could not possibly be machined on such shop tools as the lathe, planer, or shaper. One type of machine used for this purpose is shown in Fig. 232. With such a machine, round surfaces may be ground so that the variation from the nominal diameter is less than .0001 inch.

The grinding machine consists of a strong base A, upon which there is mounted a headstock B and a tailstock C similar in action to those of an ordinary lathe. Back of this there is an emery wheel driven by a separate belt. The principle of operation, for round surfaces, is that the part to be ground is put upon the centers, and driven exactly as in the ordinary lathe. The only additional precaution to be taken is that the driving apparatus should be secure, so that there is no looseness of the parts. This insures a continuous motion for the piece with no possibility of any black-lash. The piece turns towards the operator, and the emery wheel runs in the same direction. The two surfaces of wheel and work in contact are, therefore, moving in opposite directions.

The head- and tailstocks are mounted upon a traveling table D; this table moves back and forth in the same manner as the platen of a planer. It is made to stop automatically at each end of the stroke.

When work is being done, the piece is centered, with its axis parallel to the line of travel of the table. With the piece and emery wheel in motion, the former travels to and fro in front of the lathe. The wheel is then gradually moved forward until it has ground the work down to the size required.

It is not intended that large amounts of metal shall be removed by this machine. Its object is to reduce to accurate dimensions the work that has already been turned in the lathe. The proper method to pursue is to turn the piece to as nearly the required diameter as possible in the lathe, care being taken that it is left a trifle large. This may be .01 inch on each 2 inches of diameter. The surplus metal may then be removed by grinding. In the machine illustrated in Fig. 232, the transverse movement of the wheel-stand is adjusted by a hand-wheel graduated to read to .001 inch on the diameter of the work. The machine is also provided with an automatic cross-feed, which gives a range of advance of the wheel varying from .00025 inch to .004 inch at each reversal of the table. This feed is, furthermore, so arranged that it can be automatically released at any point.

This method of finishing is also used for pieces that have been case-hardened. Case-hardening always warps the metal to

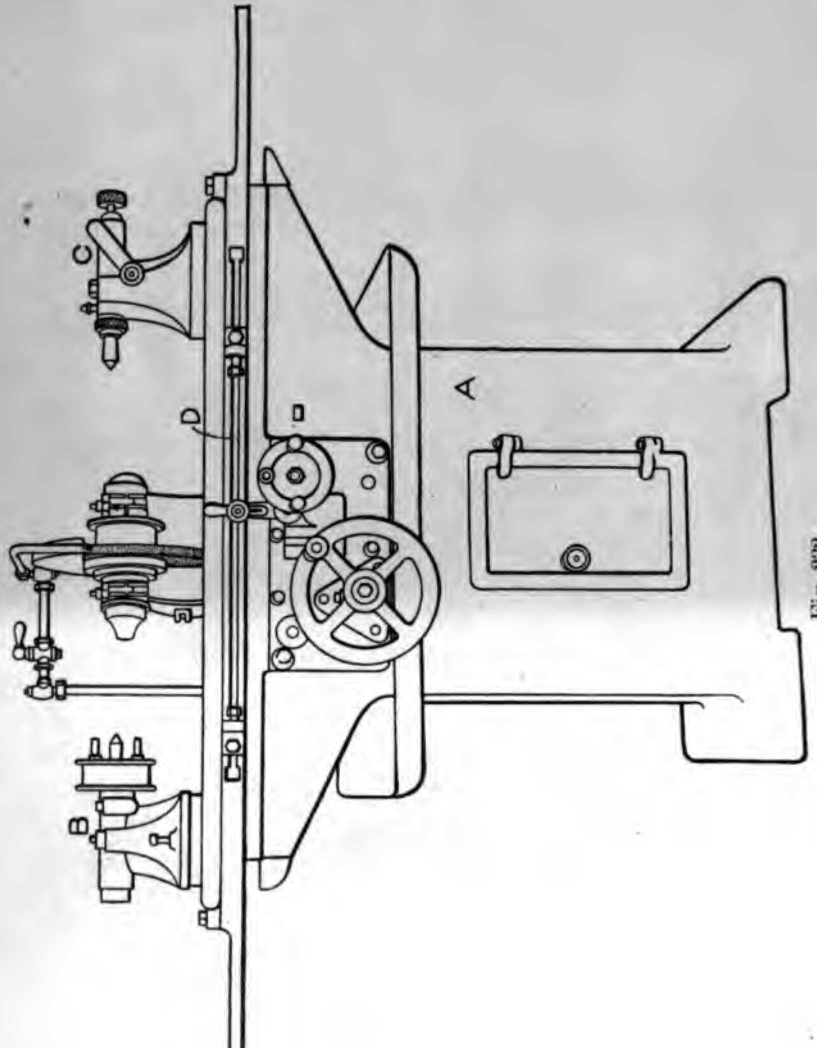


Fig. 232.

which it is applied. Grinding is resorted to in order to reduce it to the proper shape. An example of this may be taken in the method used in the manufacturing of wrought-iron locomotive crank-pins. The pin is forged and turned to as near the working size as possible. It is then case-hardened and ground to exact truth and dimensions.

Grinding is also used for truing work that comes from the lathe. The lathe does not turn its work round, owing to difference in the density of the metal, the variation of the cutting speed, the dulling of the tool, the lost motion on the centers and in the spindle, and the springing of the work itself due to the pressure of the tool.

SPEED OF GRINDING WHEELS.

Diameter of Wheel in Inches.	Maximum Revolutions per Minute.	Diameter of Wheel in Inches.	Maximum Revolutions per Minute.	Diameter of Wheel in Inches.	Maximum Revolutions per Minute.
1	19,000	5	4,400	14	1,580
1½	12,500	6	3,700	16	1,380
2	19,000	7	3,160	18	1,230
2½	8,800	8	2,770	20	1,100
3	7,400	9	2,460	22	1,000
3½	6,300	10	2,210	24	920
4	5,500	12	1,850	26	850

The grinding machine remedies this to a great extent. Partly because only a very slight pressure is brought against the work; partly because of the greater delicacy of adjustment of the grinding machine as compared with the lathe.

The method of grinding flat surfaces is practically similar to that used for round. The work is bolted to the table and moved to and fro beneath the emery wheel, which is given a transverse movement so as to cover the whole of the surface to be operated upon. The surface speed of the wheel may range from 3,000 to 5,000 feet per minute.

The above table gives the maximum speeds of caborundum wheels of various diameters.

The accuracy of grinding renders the use of fine ma tools a necessity. The micrometer caliper, especially with the vernier graduation, is best suited for this work.

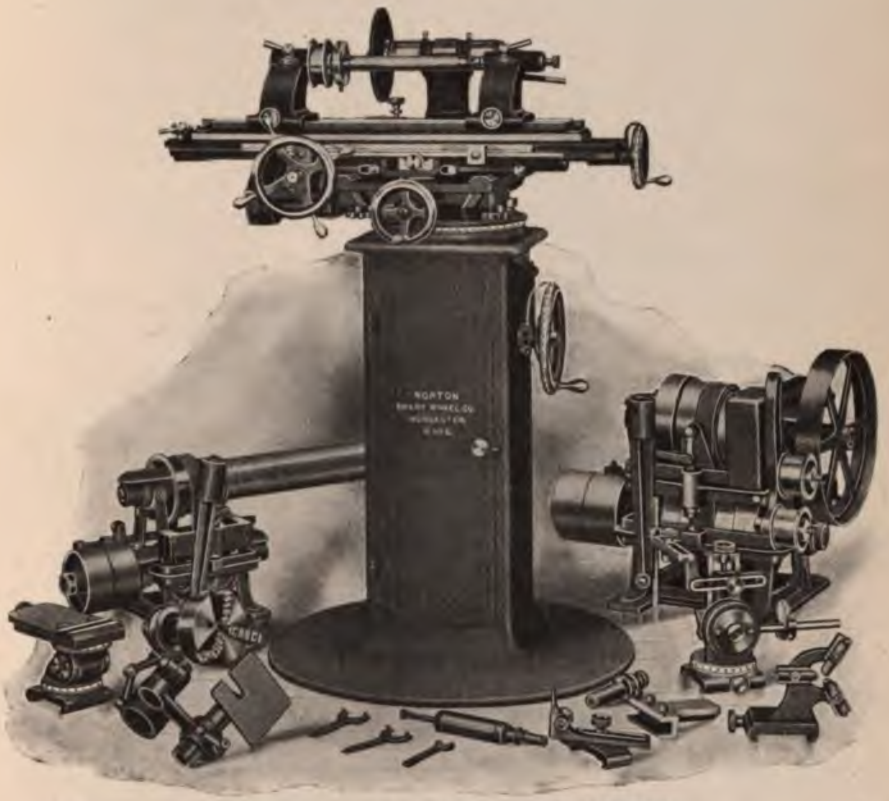
While grinding is the only method of finishing some materials, such as hardened tool steel, and the most accurate way for finishing any kind of stock, its value as an economical method is just beginning to be recognized. The general method of finishing lathe work has been to take a roughing cut with about $\frac{1}{16}$ inch feed, then a finishing cut with about $\frac{1}{100}$ inch feed, and then file to remove the tool marks. In the majority of cases it is more economical as well as more accurate to take a roughing cut with $\frac{1}{8}$ inch feed to within $\frac{1}{32}$ inch of the size, and then finish by grinding.

In some cases it is possible to get excellent results by grinding to size direct from the bar without previous turning.

Lapping is a term applied to a particular method employed in the grinding out of holes. The lap consists of a cylinder of soft metal run rapidly inside the hole to be lapped and covered with emery and oil at the same time. The surface of the lap should invariably be of soft metal. It may be made of copper, or it may be an iron bar with a covering of lead or tin. It should be turned slightly tapering at each end, so that it will enter the hole. At the middle, it should be a tight fit.

The end of the bar is run through the hole and set on the lathe centers with a dog to drive it like an ordinary mandrel. It is covered with oil and sprinkled with emery. The lathe is then run at a high speed and the work moved to and fro over the lap. Light pieces may be held in the hand. When this is done, care should be taken to turn the piece so that the grinding may be even over the whole circumference. The tendency is, when holding work in the hand, to allow it to rest upon the top of the lap; this causes the grinding to be done on one side of the hole unless the piece is frequently turned. Laps may be used for grinding holes true and parallel. For this purpose the work should be accurately centered with the lap and firmly bolted to the lathe carriage. The lap is then run at a high speed and the work moved to and fro over it.

Laps are sometimes used for grinding flat surfaces. In such cases they are in the form of disks. They are put on the lathe



UNIVERSAL TOOL AND CUTTER GRINDER.
Norton Grinding Company.

spindle in the place of the faceplate. The work is then pressed against the disk. As the outer edge of the disk has a higher speed in feet traveled per minute than those portions nearer the center, the grinding is more rapid at the edges. The work must, therefore, be constantly turned if it is held in the hand. The best way is to clamp it firmly on the lathe carriage, and press it against the lap by means of the hand feed.

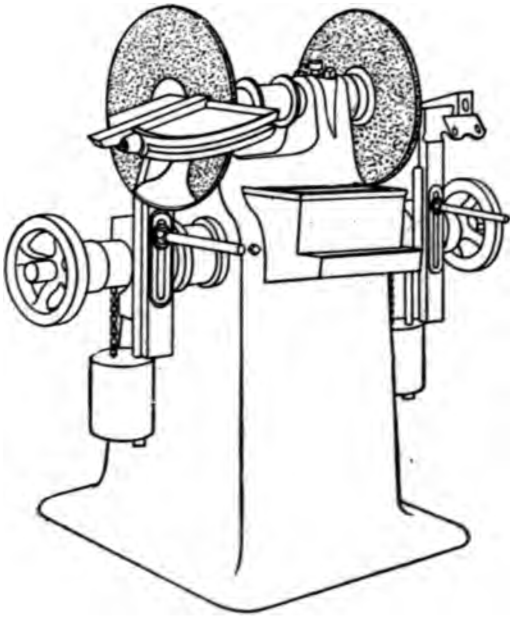


Fig. 233.

Laps for flat surfaces have grown in favor so rapidly that special machines have been made to do this work. The construction of the disk grinder can be so readily seen from the illustration (Fig. 233), that a detailed description does not seem necessary. For finishing small flat surfaces, especially those which have been hardened, this machine has become an important factor in the modern shop.

LAYING OUT WORK.

Laying out work is one of the most important details of machine shop practice. Ordinarily all work is laid out. The exceptions are where certain pieces are worked from templets, and in these cases the templet is laid out from certain points on the casting, forging, punching, or whatever is used for the work in hand.

The simplest form of laying out work is to be found in the centering of round bars that are to be turned in the lathe. In this case the end of the piece is chalked. Use a pair of hermaphrodite calipers, set the points A and B so that their distance apart is a little more than the radius of the piece. Place the caliper leg at three points on the circumference, A, B, and C (Fig. 234), and describe from each the arcs of circles A′A′, B′B′, and C′C′, respectively. Then with the prick punch mark the point indicated by the small circle in the center. This will be the center. To test its accuracy, place the divider leg in the prick punch mark and see if the caliper leg will just touch the bar over its whole surface.

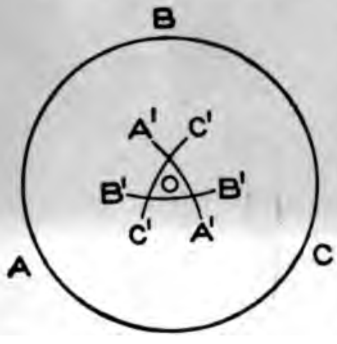


Fig. 234.

Before drilling, the center should be emphasized with a center punch.

The center square may be used for this operation, as the center can be easily located at the intersection of two diameters drawn nearly at right angles. In some cases it is better to lay the shaft in V blocks on a plate and use the surface gauge, drawing at least two lines through the center of the piece.

It is usually necessary to cover the surface of the work where lines must be visible, with chalk, white lead, or copperas, before any laying out can be done; but in cases of this kind it is usual to mark directly upon the end of the bar. Before drilling, the center should be emphasized with a center punch.

The locations for holes should be at the intersection of lines in order to be plain. After marking the center with a prick punch, take a pair of dividers and scribe a circle on the prepared surface concentric with the center already located. This circle should be about the diameter of the hole to be drilled, and in many good shops it is the custom to draw another circle concentric with the first and about $\frac{1}{8}''$ larger in diameter. This outer circle is called the reference circle, and is for the benefit of the inspector when it becomes necessary to place the responsibility for a misplaced hole. These circles may be marked with at least four prick punch marks, as shown in Fig. 168, in order to indicate the position of the circle in case of the obliteration of the line. The center is then deepened by the center punch and the hole drilled. In laying out work, the first thing to do is to "snag" the work; that is, remove the ridges of the casting caused by the pattern being made in two or more parts. For small castings a coarse file is generally used, while for large work the cold chisel is used. In many shops the cold chisel is operated by compressed air.

In laying out work for the planer and milling machine great care must be exercised. It is necessary that there should be a base line to which the lines may be referred. It depends on the character of the work as to how this should be done. Sometimes it is quite sufficient to lay off the base line parallel to one side of the casting or forging. If the side thus used is to be finished, then the base line should be located at the proper distance from it to allow for the finishing. The amount required varies with the character of the casting or forging; this has been fully explained. Usually there is some outline of the rough piece that will serve as a guide.

As an example of the laying out of work, take the valve and steam chest seats shown in Figs. 235 and 236. The work is to be done on a planer. The cylinder has probably been bored. It is then placed on the planer, and so set that the center line through the cylinder is parallel to the platen of the planer. The first machine work to be done is the taking off of the roughing cut from the face A. This face is to be planed down to a certain height above the cylinder center; this height may be marked o the edge of the valve seat by the prick punch mark B. If the surface C is to be planed at the same time, its height is indicated by the prick punch mark D. These points may be located by means of the surface gauge. Set the gauge on the platen and

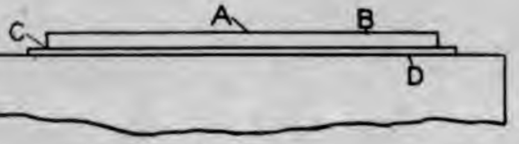


Fig. 235.

elevate the point to the proper height. Move it so that it will touch the side of the casting at the proper point, and make the marks B and D accordingly. When the surfaces A and C have

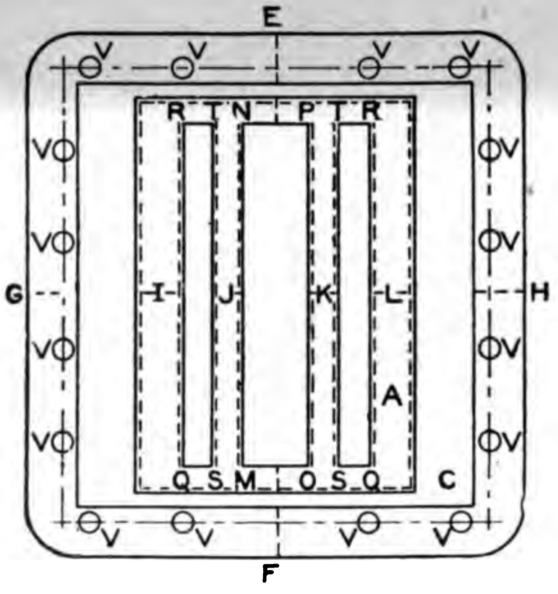


Fig. 236.

received the roughing cut, the plan may be laid off as in Fig. 236. With a square having a suitable length of blade, locate the points G and H directly over the center line of the cylinder. Cover the surfaces A and C with chalk where lines are to be drawn. Draw the lines I, J, K and L on the surface A, between G and H. Through the center of the side of the exhaust port draw the lines E and F at right angles to GH. This is done with a scriber. Lay off half the width of the exhaust port on either side of E and F, and draw the lines MN and OP parallel to E and F. In like manner, draw the lines QR and ST for the limits of the steam ports. All of these lines are to be emphasized by the use of prick punch marks as indicated.

If the sides of the valve seat are to be finished, the line to which the metal is to be cut is indicated in the same manner. Finally the holes VVV, etc., for the holding down studs of the steam chest, are to be laid out. The center lines are first drawn; then the centers of the holes are marked. After which the circles for the holes are drawn as already described.

Work is rarely laid out for the lathe. It is not necessary that it should always be done for the planer. Laying out is employed where accuracy is essential, and, where it is possible to secure the proper dimensions, with the piece to be operated upon in position on the machine.

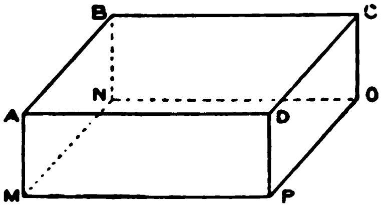


Fig. 237.

The man who has charge of the work of laying out should have some knowledge of the elementary principles of geometry, he should also have some knowledge of drawing, and should, of course, be able to read drawings.

A few general suggestions may be given regarding work to be finished in the vise on either the planer, shaper, or the milling machine, where several faces are to be finished at right angles to one another. Referring to the rectangular block of Fig. 237, the block is first placed in the vise with the face MNOP down, and the face MADP against the fixed jaw. The face ABCD is then machined, and the work turned so that ABCD is against the fixed jaw and MADP down. With the block in this position, NBCO is worked, making NBCO at right angles to ABCD. With ABCD still against the fixed jaw, and

NBCO down, surface MADP is next worked. This brings two edges at right angles to the same side and parallel to each other. Then, placing ABCD down and either MADP or NBCO against the fixed jaw, surface MNOP is generated parallel to ABCD. This leaves the ends to be finished. The vise is swung so that the fixed jaw is at right angles to the line of motion of the tool, and on the planer and shaper, they are finished by using the vertical feed. In the two last named tools, the tool holder is swung so that the tool will clear the work easily on the return stroke.

In working cast iron, it is well to chamfer the edges with a file. If this is not done, the metal will break off when the tool reaches the end of the cut, leaving a ragged edge. The depth of the chamfer depends on the amount of metal to be removed.

Fitting is the term generally applied to the hand work necessary in assembling machinery after all the machine work has been done. Filing, either in the vise or lathe, and scraping are the operations usually required, although the hammer and chisel are sometimes used. As hand work costs much more than machine work, the machining is done as closely as possible to make the hand work a very small item.

SHOP SUGGESTIONS.

In the regular work of any shop, occasions are constantly arising for the determination of the best method of doing work. The success with which the desired end is attained depends upon the skill and judgment of the man in charge. While it is impossible in a limited space to give instructions regarding every possible emergency that may arise, a few suggestions regarding shop practice will be valuable.

Pening consists in the stretching of the metal on one side of a piece of work in order to alter its shape. There is a wide difference between pening and bending. For example, suppose the curved or warped piece in Fig. 238, is to be straightened. If it were to be bent until it were straight, it would be placed on the blocks A with the concave surface down, as shown by the dotted lines. It could then be struck by the hammer and driven down past the line of support, and strained so that it would remain approximately straight. Such a method of straightening could not be applied to a piece of complicated outlines. It would remain wavy. In pening to truth such a piece as shown in Fig. 238 it is laid on an anvil with the convex surface down. It is then struck with the pene of the hammer on the concave side. The blow must be quick and sharp. The result is that the metal is stretched at the point where the blow is struck. By working successively over the whole surface the concave side is stretched so that it is equal, in its dimensions, to the convex side. The piece then becomes straight and will so remain. A skillful use of the hammer will straighten almost any warped piece of thin metal.

Drilling Hard Metals. It is sometimes desirable to drill a hole in very hard metal. To do this the drill must be made very hard; it must be run at a very slow speed; it must be forced against the work as hard as possible without breaking the point, and it must be provided with an abundant supply of oil. For excessive hardening of a drill, it may be heated to a dull red heat, preferably in a charcoal fire, and quenched in mercury instead of water. It will also assist in the operation if the surface of the metal to be drilled is nicked with a cold chisel before work is begun. In some cases turpentine, in place of oil, may be used with beneficial results.

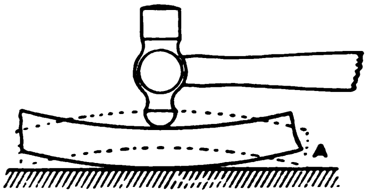


Fig. 238.

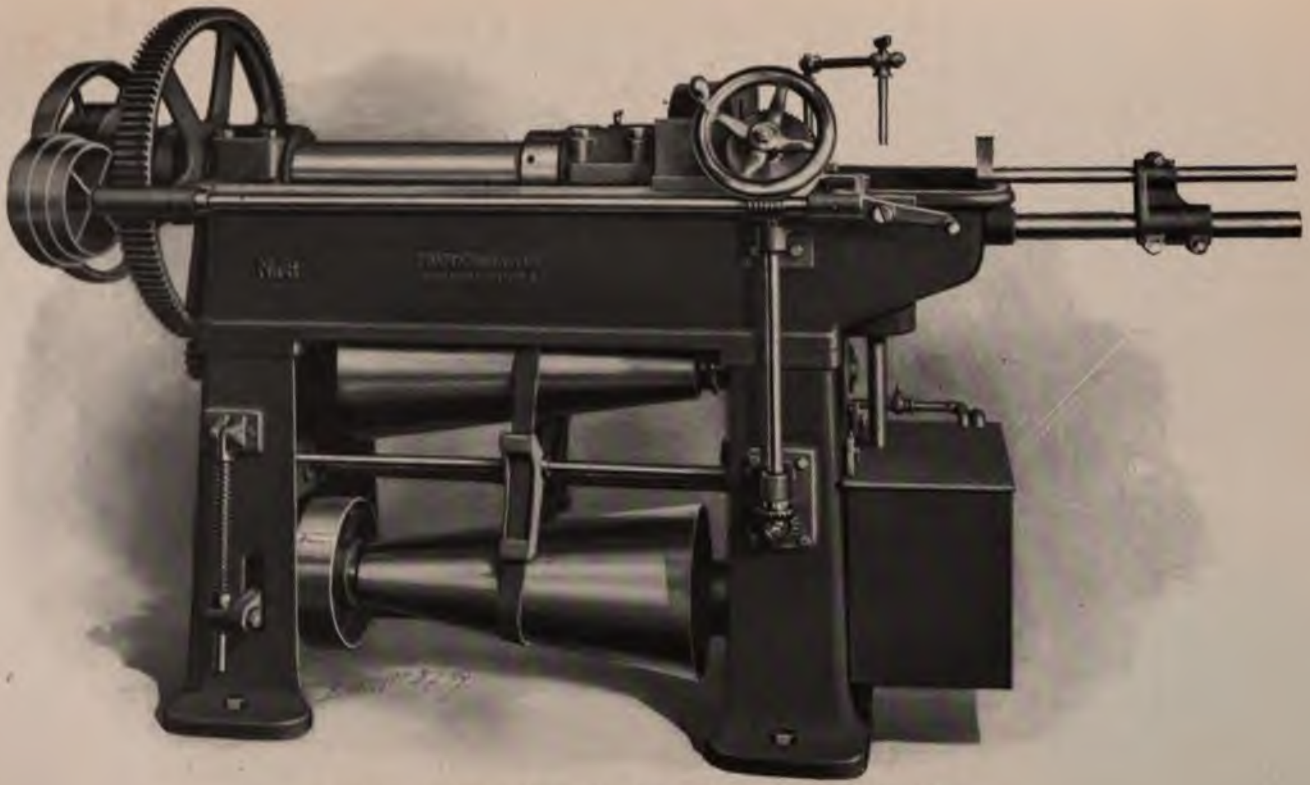
Thin chilled cast iron may be softened by placing a small piece of sulphur on the place where a hole is desired and then heating slowly to a dull red.

Glass may also be drilled. There are two methods: one is to use a flat drill moistened with camphor and turpentine, and the other is to use a copper tube with No. 60 emery or carborundum and oil. In the last method, drill half-way through, reverse, and drill to meet, removing the fin at the center with a round file wet with water or turpentine.

Grinding Valves. This is a kind of grinding that is usually done by hand. It consists of fitting a valve and its seat so that they are in metallic contact. In its results it is the same as scraping. The process is very simple. The valve is coated with oil and some fine emery sprinkled over it. It is then put on the seat and worked back and forth or revolved. The emery serves to grind off the high surfaces of each. After grinding for a time, remove the valve and wipe both surfaces clean. The metal on each will show where they have been in contact. When these indications appear over the whole of the surface, or in a continuous ring about the seat of a circular valve, the work is completed.

To generate a surface plate it is necessary to work with three at the same time. For the sake of making the explanation clear they will be called A, B, and C. After the plates have been planed, a straight edge should be laid on each. A straight edge is merely a piece of flat steel having one or both edges true and straight. Set the straight edge on the plates in all directions. If it touches over its whole length in all positions, then the plates are ready for scraping. If it touches at the edges of the plate and is clear in the center, the former are high and should be filed down. If it touches in the center and rocks to and fro, the plate is convex and the center must be filed down. After the plates have been filed to truth as far as truth can be indicated by the straight edge, they are ready for scraping.

Now take plates A and B and place them face to face. Strike a blow on the upper one, and it will cause a jarring sound to be heard. This shows that the two are not in perfect contact. Smear the surface of plate A with a thin mixture of red lead and oil. Cover the surface evenly and thinly. Then rub the two plates together, and where the red lead rubs off on to the surface of plate B the two come in contact. Take the scraper and scrape off a little of the metal from each of the plates where they have been in contact. Wipe off plate B, and again smearing plate A, proceed as before. Continue this process until the two surfaces are in contact over their whole areas. This does not prove, however, that they are flat. They may be in contact, as required, if A is convex and B is concave. To test this the third plate is necessary. Smear plate B with red lead and scrape C to fit it. Do not touch A. It is evident that A and C will then be alike. Bring them together. If they are both convex they will roll over each other. If they are concave they will bear at their edges and



CUTTING-OFF MACHINE WITH INCREASED SPEED MECHANISM.
Pratt and Whitney Co.

not touch in the center. They will appear to be out of truth by twice the actual amount. Scrape off the contact points of A and C. Remove as nearly as possible the same amount of metal from each. When these two plates have been brought so as to be in contact over their whole areas, lay plate A aside and scrape B until it fits C, but do not touch A. Then try A and B together. If they do not touch over their whole areas, treat them as before described for A and C. Then introduce C again. Continue this alternating process until the three plates form a bearing over the whole of the surface of each of the other two.

During the latter part of the process, use alcohol instead of red lead. This will leave clean, bright spots at the points of contact.

Fitting Brasses is a piece of work that is now usually done on a machine, but which is sometimes done by hand. Brasses that are to be used for connecting rods, and which are made in two pieces as shown in Fig. 239, have a tendency to warp after the machine work has been done upon them. The difficulty arises from their closing along the diameter A. Thus if the brass is finished, and the hole bored out to the proper diameter, and is then cut apart on the line CD, it will be found, shortly afterwards, that the diameter A is less than the diameter B. It may, therefore, be necessary to bore the hole somewhat larger than the working diameter. The kerf made by the saw will usually allow the parts to be drawn together along the diameter B so that it will more than make up for the shrinkage at A. The hole can then be scraped to fit the pin. The brasses should always be keyed solidly metal to metal. This avoids a wear of the sides and edges of the metal due to the thrust of the rod.

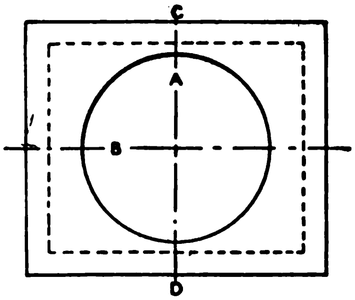


Fig. 239.

Joints. Where a gas or liquid is to be retained in a pipe or other vessel without leakage, a tight joint is necessary. The method of grinding valves to their seats has already been explained. In that case it was shown that a metallic contact between the valve and its seat is all that is required in order to make it a tight joint. Two surfaces that have been scraped to fit will also accomplish the same purpose. This is frequently too expensive an operation to be performed, especially on rough work. In such places a soft material may be interposed between the two surfaces. Where the joint is to be a permanent one and is not to be taken down, the red lead joint is usually employed. This consists in the use of a mixture of red and white lead between the joints. To ordinary white lead ground in oil add enough dry red lead to make a paste that can be spread without sticking to the blade with which it is applied. After the mixture has been made, it will be improved by pounding it well with the hammer. It may then be laid between the two pieces of metal forming the sides of the joint and the latter be drawn together. Red lead joints are extensively used in pipe fitting. The red lead has a tendency to rust the iron with which it is in contact, and thus form a very tight connection between the two pieces. Where provision is to be made for taking down the joint at a future time, it is better to use a graphite paste made for the purpose. This does not rust the metal; it forms a perfectly tight joint and one which may be taken down without difficulty at any time.

Joints that are subject to occasional disconnecting can be best held by a disk of rubber packing. The latter is cut to fit the flanges between which the joint is to be made, and they are then drawn tightly together.

Joints that are to be frequently taken down are usually packed with a piece of copper wire. Such a place is the joint between the steam chest and cylinder of a locomotive engine. A groove is cut in the two surfaces and a copper wire is laid therein. This wire should be about $\frac{1}{4}$ inch in diameter. Its size, however, depends upon the joint to be packed. The ends of the wire are soldered together so that no leakage may occur past the ends.

Another form of joint is the rust joint. This is always permanent in character. The making of such a joint consists in rusting the two surfaces together. The following are the proportions by weight of the rusting material: 100 parts of iron turnings; 1 part of sal ammoniac, and ½ part of sulphur. The setting of the joint can be hastened by increasing the amount of sal ammoniac from 15 to 25 per cent. Mix the ingredients thoroughly and just cover them with water.

Fluting Rollers. Where feed rollers such as those used in wood-working machinery are to be turned and fluted, the turning should always be done first. This insures a continuous surface for the cutting tool. Where old rollers are to be re-turned and fluted, the same rule applies. The fluted surface may be turned to size. The lathe tool will break the edge of the ribs away, but when the fluting is done, these edges are again made smooth. The fluting can be done on a planer with a round-nosed tool. The roller should be held on centers and clamped so that each groove may be presented to the tool in succession. A planer center, as illustrated in Fig. 178, affords a convenient method of holding and turning the work.

Scale. Whenever a piece of cast iron is to be turned, the point of the tool should always be made to work beneath the scale. The scale is the hard outer shell that covers all cast iron as it comes from the foundry. It is very hard and brittle. If the edge of the tool is made to work in or against it, that edge will soon be dulled. If it is beneath it, the raising of the chip cracks and removes the scale.

Pickling. Where castings are to be worked, either in the lathe or planer, to dimensions only a little less than that when rough, they should be pickled. This consists in washing them with a solution of sulphuric acid and water. The castings may be either submerged in or swabbed with the solution. The effect of pickling is to cause the scale to drop off in flakes, leaving the metal bare, unprotected and rusty. The casting should then be washed with a sal soda solution. A good solution for this work is to use 1 part of commercial sulphuric acid in 10 parts of water.

Cold Chisels. It is well to use a coarser grade of steel for cold chisels than for lathe or planer tools. A coarse-grained metal is preferable because the continual hammering in use and redressing will gradually modify the granular structure until it is microscopic in its fineness. In dressing, it should never be heated above a cherry red, and the temper should be drawn well down

Ordinary tubes are fastened to the end plates by expanding the metal of the tube against the tube plate. This is done by a tool called an expander, of which there are two common forms. One form consists of a steel taper pin and a number of steel segments, held in place by a spring. The outside of the segments have the form to be given to the expanded tube, and the inside is a straight hollow cone, into which the steel taper pin fits. The segments are forced apart by hammering on the steel pin. In order that the metal of the tube may not be injured, the hammering should be done gradually and carefully, and the expander turned frequently. Another form, shown in Fig. 39, has a set of rolls that are forced against the inside of the tube by driving in the taper pin. The pin and rolls rotate as the pin is driven, and the rolls gradually expand the tube against the tube plate.

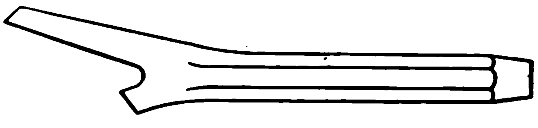


Fig. 42.

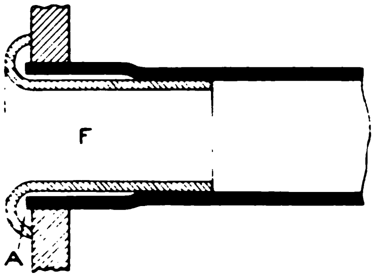


Fig. 43.

Two forms of tube expansion are shown in Figs. 40 and 41. That shown in Fig. 41 is preferable to that in Fig. 40, as the latter bears at the corners only, while the former bears against the entire thickness of the tube sheet.

After the tubes are expanded, the ends are beaded over, as shown in Figs. 40 and 41. This adds to the strength of the connection between the tube and tube sheet. The tool commonly used for this beading is shown in Fig. 42.

Ferrules are often placed in the ends of fire tubes, and serve to protect the ends from the intense heat of the fire. The arrangement is shown in Fig. 43, the ferrule F being placed within the tube for a short distance. The space A is merely an air space.

Stay tubes are not used as extensively at the present time as they were formerly. They were very common at a time when the holding power of expanded tubes had been experimented on but little. It is now apparent from such tests that the holding power of tubes expanded, as shown in Fig. 40, is more than equal to the pressure on the spaces between the tubes of an ordinary tube plate. Stay tubes are simply heavier tubes, with the ends projecting beyond the tube sheet and threaded for shallow nuts. The ends of the tubes are frequently upset or thickened, and screwed into the tube sheet as well. This form is shown in Fig. 44.

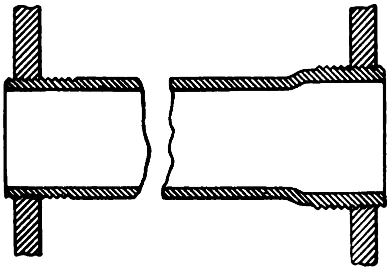


Fig. 44.

FURNACE FLUES.

Flues which are subjected to external pressure should always be cylindrical. Fig. 45 shows the section of the Adamson flue. This was an improvement over the plain furnace, as it is more elastic and allows expansion; the flanged rings also strengthen and stiffen it against collapse. The methods of building furnaces shown in Figs. 46 and 47 are not considered as good as the Adamson arrangement. Fig. 46 is too rigid, and does not

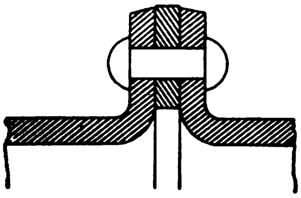


Fig. 45.

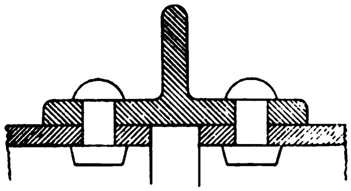


Fig. 46.

machine is then lined and leveled as already suggested, but the bottom of the machine is usually a rough casting, the top of the stone foundation is still rougher, and as the wedges are likely to slip out under the jarring of the machine, a permanent support must be provided. This may be done by pouring melted sulphur beneath the bed. To do this, build a dam of clay or sand all around the bed and about 2 inches high. Melt ordinary stick sulphur or brimstone in ladles, and pour in at several points at once. Keep the space flooded until the dam is well filled, and allow it to harden. This will occur very quickly, after which the dam may be removed and the sulphur cut away from the edge of the machine. Care must be taken that the temperature of the sulphur is as high as possible before pouring. Unless this is done it will cool and set before reaching the inmost recesses beneath the machine. It will then crumble because of insufficient bearing surface to carry the imposed weight. The nuts are then screwed down on the bolts and the machine is secure.

Belting. The shafting and machines are usually driven by belting, and a few remarks on this subject may be desirable. Leather is the material generally employed, and the belting may be from single to six-ply in any suitable width. Single belting has a flesh and a grain or hair side, and should be run with the grain side in contact with the pulley. The ends are cut square, and fastened by hooks, coiled wire, or rawhide lacing.

Leather belting is injured by water, steam, oil, and temperature above 110° F. Where such conditions exist, cotton belts, faced with thin leather, or rubber belts may be used. These belts are cheaper than leather, are about as strong, and will transmit power as effectually; but they will not stand mutilation of the edges. This is a point of prime importance, and prohibits their use in many cases.

The power transmitted by a belt is directly proportional to its speed and width. A safe rule is to allow one horse-power for a speed of 1,000 feet per minute, with a single-thick belt one inch wide. This is a more liberal allowance in favor of the belt than is usually given, but will increase the life of the belt in far greater proportion than the increase in first cost. Double belts will transmit about one and one-half times as much power as single belts. The above rule applies to belts running over pulleys of equal diameter, or, in other words, to cases where the arc of contact is 180°. For smaller arcs of contact use the coefficients found in the following table:

90°	100°	110°	120°	130°	140°	150°	160°	170°	180°	200°
.65	.70	.75	.79	.83	.87	.91	.94	.97	1.	1.05

To increase the power transmitted, either increase the speed of the belt by using larger pulleys, or use a wider belt.

A 3-inch single belt is running over a 24-inch driving pulley which makes 200 R.P.M. (revolutions per minute). How many H.P. will it transmit?

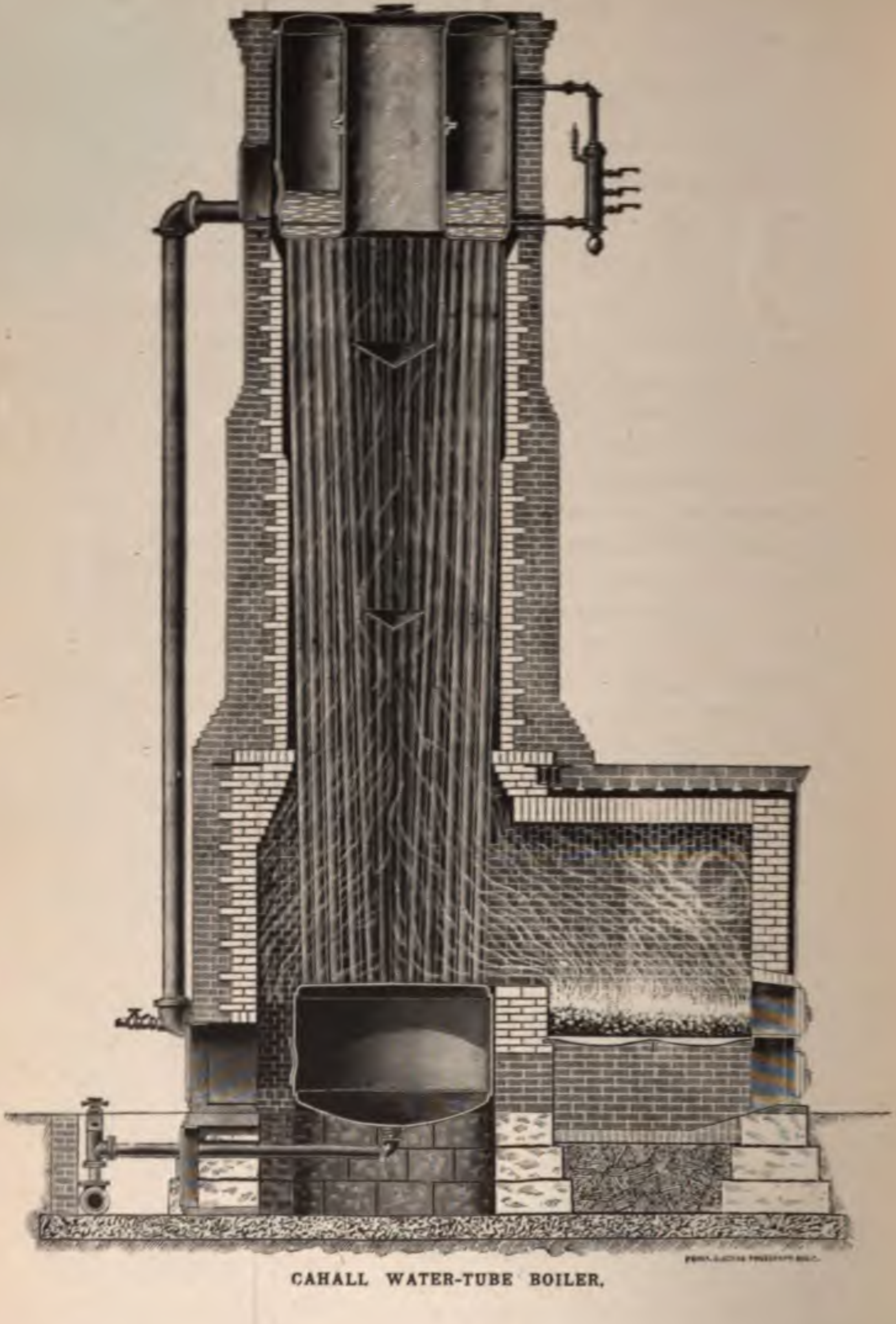
The circumference of the pulley in feet is 2 × 3.1416 = 6.2832 feet. As the speed of the pulley is 200 R.P.M., the speed of the belt will be 200 × 6.2832 = 1256.64 feet per minute. For every inch of width it will transmit 1256.64 ÷ 1000 = 1.25664 H.P. Then a 3-inch belt will transmit 3 × 1.25664 = 3.76992 H.P. *Ans.* 3.75 H.P. (approx.).

It is desired to increase the H.P. in the above example to 5 H.P. How may it be done?

(1). By using a wider belt in the proportion of 3.75 to 5. 3.75 : 5 : : 3 : 4. *Ans.* By using a 4-inch belt.

(2). By using a larger pulley in the same proportion. 3.75 : 5 : : 24 : 32. *Ans.* By using a 32-inch pulley.

(3). By using a double belt. 1 : 1.5 : : 3.75 : 5.63. This would give a little better result than required.



CAHALL WATER-TUBE BOILER.

CONSTRUCTION OF BOILERS.

A steam boiler, or steam generator, consists of a vessel tc contain the water and the steam after it is formed; a fire-box to contain the fire; tubes, flues and uptake to transmit heat and conduct the hot gases from the fire to the chimney, and various fittings to facilitate the safe and economical operation. Boilers are often classified according to their uses and conditions; thus we have stationary, marine and locomotive boilers. Boilers having a shell partially filled with tubes, through which the hot gases pass, are called tubular, fire-tube or shell boilers; and those having a large flue in which is placed the fire, are called flue boilers. If the tubes are filled with water and the hot gases are outside, the boiler is called a water-tube boiler.

Steam boilers are made in a variety of shapes, according to the type, uses and conditions. Let us first consider boiler construction in general, leaving out the peculiarities of marine, locomotive and water-tube boilers.

MATERIALS.

The materials of which boilers are constructed are exposed to conditions which weaken them and shorten the life of the boiler. Among these conditions are corrosion, both external and internal, high pressure, and expansion and contraction, due to varying temperature and pressure.

Cast iron was the material of which the earliest forms of boilers were made, but on account of its low tensile strength and its unreliable nature, it is now but little used, except for parts of water-tube boilers, and sometimes for the ends of low-pressure cylindrical boilers and for fittings. It is cheap and resists corrosion

ccount of its unreliability and brittleness, the parts must

hick and therefore heavy.

Wrought iron, up to about 1870, was the principal material used for boiler plates. It is a pure iron prepared from pig iron by a process called puddling, described in "Metallurgy." Wrought iron is well adapted for use in boiler construction, as it is strong, tough and fibrous, and combines high tensile strength with ductility and freedom from brittleness. When the properties mentioned are well combined, wrought iron will resist strains due to unequal expansion. Boiler fastenings, stays and other parts made by welding are sometimes made of wrought iron. It is customary to consider that a bar loses about one-quarter of its strength by welding, although it is often stronger in the weld, owing to the working of the metal during the welding process.

Steel has entirely displaced iron for boiler-shell work. Boiler steel is made by the open-hearth process, and contains for ordinary thickness of 1 or 1¼ inches 0.25 per cent carbon, while thinner plates of ¼ inch should not contain over 0.15 per cent carbon. Larger percentages of carbon, while accompanied by an increase in tensile strength, lessen the ductility. The following properties show steel to be the best boiler material at present: great tensile strength, ductility, homogeneity, toughness, freedom from blisters and internal unsoundness. Blisters and unsoundness are faults sometimes met with in wrought-iron plates.

Copper in many respects is superior to wrought iron for boiler construction. It is homogeneous, resists oxidation (the corrosive action of most feed waters) and incrustation. It is more ductile and malleable and a better conductor of heat, which not only gives it a higher evaporative power, but also enables it to last longer under the intense heat of the furnace. Its disadvantages are its low tensile strength, about 30,000 pounds per square inch, and its decrease of strength with an increase of temperature. In heating from the freezing point to the boiling point it loses 5 per cent of its strength, and at 550° F. it loses about one-quarter of its strength. For these reasons and on account of its high price, it is now seldom used in boiler work.

Brass is an alloy of copper and zinc in which the proportions
of each var The red color comes from a larger per
and more expensive than yel-
gauges and other fittings.

Bronze is an alloy of copper and tin, and is advantageously used for valves and seats of safety valves where the wear is great.

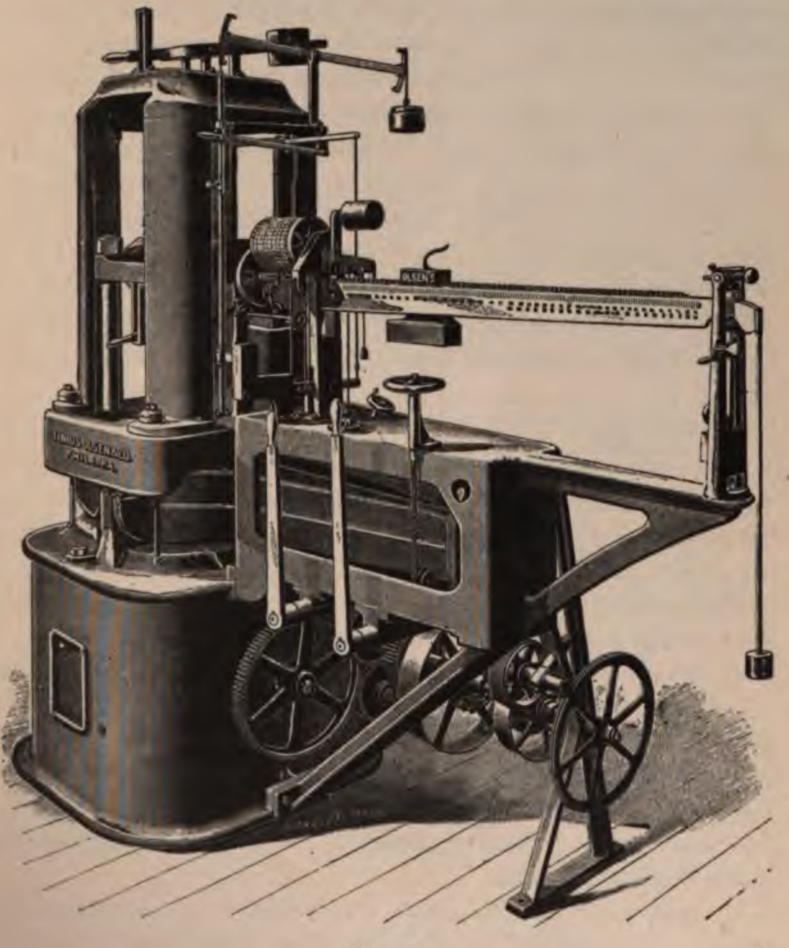


Fig. 1.

TESTING MATERIALS.

In order to determine the strength and the other qualities of the materials, specimens are tested. The results of these tests show the ultimate tensile strength, elastic limit, contraction of area and elongation.

The simplest way to test a piece of iron bar or plate would be to fix it firmly at the upper end and hang weights on the other end, adding other weights until the bar is broken. This is but a crude method, and in order that the elastic limit and elongation may be determined at the same time, testing machines are used. There is a large variety of testing machines, adapted for various materials, but the general principles are the same.

Testing Machines. The testing machine consists of a frame and two heads, to which the ends of the test piece are fastened by wedges or other devices. By means of steam or hydraulic power one head is drawn away from the other for tensile tests. The pull is transmitted to some weighing device, usually levers and knife edges like the beam of ordinary platform scales. In small machines the pull may be applied by a lever.

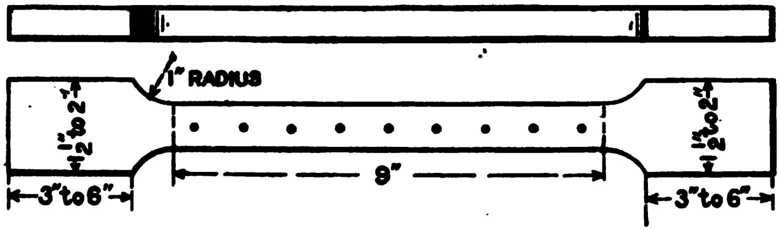


Fig. 2.

Testing machines are made for all varieties of testing: tensile, compressive and shearing stresses. Also for deflection of beams and for strength of wood, cement, brick and stone. Fig. 1 shows an Olsen testing machine designed for tensile and compressive tests of iron and steel.

In order to test materials, test pieces or specimens are prepared. For testing iron plate the test piece should be at least 1 inch wide, about 2 feet long and planed on both edges. Many engineers recommend these dimensions. According to the Board of Supervising Inspectors of Steam Vessels, the test piece should be 10 inches long, 2 inches wide and cut out at the center.

To ascertain the tensile strength and other qualities of steel, a test piece should be taken from each plate. These test pieces are made in the form as shown in Fig. 2. The straight part in the center is 9 inches long and 1 inch wide; and to determine elongation it is marked with light prickpunch marks at distances 1 inch apart, the marked space being 8 inches in length. The ends are $1\frac{1}{2}$ inches to 2 inches broad and 3 inches to 6 inches long.

As has been explained in "Mechanics," the force necessary to break the piece is the proportionate part of the tensile strength per square inch. Thus if the test piece having a reduced section of .4 square inch is broken at 19,200 pounds, the tensile strength of the plate is $\frac{19{,}200}{.4} = 48{,}000$ pounds per square inch.

EXAMPLES FOR PRACTICE.

1. If a piece of boiler plate breaks at 33,500 pounds and the reduced section is $1\frac{1}{8}$ inches by $\frac{1}{2}$ inch, what is the ultimate tensile strength?

Ans. 59,555 pounds.

2. A boiler plate is claimed to be of 64,000 pounds tensile strength. If the section is 1 inch wide and .63 inch thick, what should be the reading of the testing machine when the specimen breaks?

Ans. 40,320 pounds.

3. A test piece of the form shown in Fig. 2 measured 8 inches between the prickpunch marks before testing and 9.56 inches after testing. What was the per cent of elongation?

Ans. $19\frac{1}{2}$ per cent.

4. If the area of section before breaking is .4825 square inch and after breaking is .236 square inch, what is the per cent of reduced area?

Ans. 51 per cent.

STRENGTH OF BOILER MATERIALS.

The crushing strength of cast iron is high, varying from 50,000 to 75,000 pounds per square inch; its tensile strength is low, varying with the chemical and physical properties of the iron from about 15,000 to 22,000 pounds per square inch.

Wrought-iron plates having a tensile strength of from 50,000 to 60,000 pounds, with an elongation or ductility of from 20 per cent to 30 per cent, are suitable for boiler work. Boiler iron may be such machine work as is required for fittings, furnace fronts, etc., and a system of cranes for handling and transporting material. In connection with the above is a storeroom of sufficient size, a forge shop, and an engine and boiler for supplying the shop with the power necessary to operate it.

In boiler-shell work drilling has entirely displaced punching, and to-day all holes are drilled. Punching is cheaper than drilling, but it is more injurious to the plates and not as accurate. It is easy to see that drilling rivet holes, even if twenty are being drilled at once, is done with less strain on the plates than when done by a multiple punch forcing several holes at once. The force required to punch a plate gives the best idea of the harm done to the plate. Experiment shows that the resistance of a plate to punching is about the same as its resistance to tensile tearing. Suppose this to be 50,000 pounds per square inch; then the force required to punch the plate is the area cut out times the shearing strength, or $d \times \pi \times t \times 50{,}000$.

In which formula

d = diameter in inches and

t = thickness in inches.

For a hole $\frac{3}{4}$ inch in diameter in a $\frac{1}{2}$-inch plate, the force will be

$$\tfrac{3}{4} \times 3.1416 \times \tfrac{1}{2} \times 50{,}000 = 58{,}900 \text{ pounds.}$$

If the force required to punch one hole is 58,900 pounds, the force required in punching several holes by means of a multiple punch is enormous.

A good, ductile plate is but little injured by punching; but if of a hard, steely nature, it is likely to be seriously injured. For this reason wrought-iron plates are usually punched and steel plates are drilled. On the whole, a drilled plate is somewhat stronger than a punched plate for any kind of joint.

Some boiler makers punch the rivet holes slightly smaller than the desired size and then ream them out. By this process the injured metal around the holes is cut away. Another method to overcome the injurious effects is to anneal the plate after punching.

The ordinary process of annealing consists of heating the plate to red heat, and then allowing it to cool slowly. By this

12. When is it advisable to use milling-machine cutters having interlocking teeth ?

13. When is it advisable to use milling-machine cutters having their teeth cut spirally ? Why ?

14. When is it advisable to cut the teeth of milling-machine cutters with a right-hand spiral ? When a left-hand spiral ? Why ?

15. State advantage gained in making milling-machine cutters with nicked teeth.

16. Why is it generally considered advisable to make milling-machine cutters that are larger than 6 or 8 inches diameter with inserted teeth.

17. When a blank for a milling-machine cutter that is to have inserted teeth is milled with slots that are at angle to the cutter axis, why is it not advisable to leave the faces of the teeth at that angle ?

18. If an emery wheel, 3 inches in diameter, is used in grinding the teeth of a milling-machine cutter, how many revolutions must it make in a minute in order to run at a peripheral speed of 5,000 feet per minute ?

19. Why is it not generally considered good practice to make key ways in milling-machine cutters with sharp corners ?

20. State in your own language the generally accepted meaning of the term "formed cutter" or form cutter.

21. Name some of the advantages derived from the use of formed cutters.

22. What would be the result if the faces of the teeth of a formed mill were not recut after they were backed off ?

23. When backing off the teeth of a formed mill, what would be the result of setting the forming tool above or below the center of the work ?

24. When making milling-machine cutters with threaded holes, why is it necessary to first thread the blank, then machine it on a threaded mandrel ?

What would be the result were the cutter machined to shape before threading the hole ?

25. When machining a piece of work having a threaded hole, why is it not advisable to screw the piece onto a threaded mandrel in such a manner that the shoulder of work is against the shoulder of mandrel when squaring the first end ?

ERECTING SHOP.

E. Keeler Company.

means, hard and brittle iron or steel is made soft and tough. While the metal is hot, the surface becomes oxidized. For most purposes this scale of oxide in not harmful, but in some cases it must be removed. As this is expensive, a process of annealing in illuminating gas has been devised. The action of the gas is to reduce the oxide without altering the properties of the piece. The results obtained from annealing depend upon the kind of iron or steel, the temperature to which it is raised, and the rate of cooling. It is a great advantage to all steel of over 64,000 pounds per square inch in tensile strength, but softer steels are little better for the process.

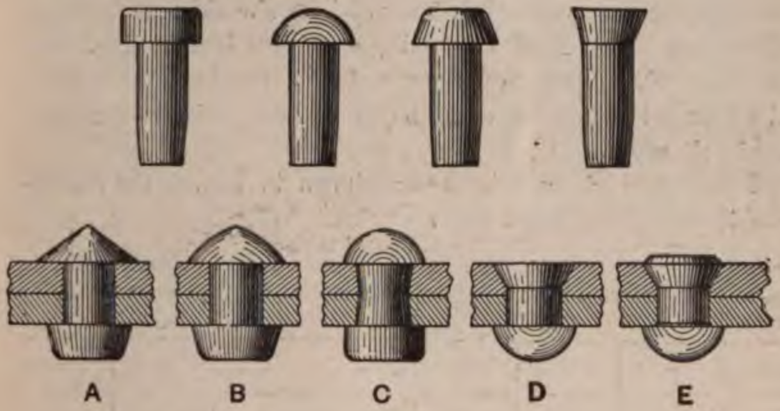


Fig. 3.

After the shell plates are planed to correct shape and the holes drilled or punched, they are put through the bending rolls and bent into a cylindrical shape, the amount of curvature being determined by a template made for the purpose. Plates are usually sheared to size, and then the edges planed with a slight bevel to facilitate calking. In the meantime the heads are being flanged by a hydraulic flanging machine; when the flange is completed, the head is put on the platen of a boring mill and turned so as to exactly fit into the shell. In some shops it is customary to punch or drill only a few holes in the shell and flange of the head, these holes serving to take bolts for holding the parts together. The back head plate is bolted into the rear course of plating, and the parts thus assembled are hoisted up to drill if the plates, etc., have not been previously drilled or punched, otherwise to the hydraulic riveter.

RIVETS AND RIVETING.

Rivets are formed by forging, from round iron bar or mild steel, with a cup or pan shaped head. The cylindrical part, called the shank, is a little smaller than the hole and has a slight taper. Fig. 3 shows common forms of rivets. As rivets are not as reliable in tension as in shear, they are used mainly at right angles to the straining force. If the stress is parallel to the axis, bolts are used, since they are strong in tension. The shearing strength of steel rivets is about 45,000 pounds per square inch, and of iron rivets about 40,000 pounds per square inch. Steel rivets are often used with steel plates, but many boiler makers prefer to use iron rivets in all cases.

Three types of rivets in use are shown in Fig. 4, the following table giving the dimensions:

Diameter of Rivet.	Cone Head. A			Countersunk. B		Button Head. C	
D	E	F	G	E	G	E	G
$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{19}{32}$	$\frac{9}{16}$	$1\frac{1}{16}$	$\frac{9}{32}$	$1\frac{1}{16}$	$\frac{7}{16}$
$\frac{11}{16}$	$1\frac{1}{8}$	$\frac{21}{32}$	$\frac{39}{64}$	$1\frac{3}{16}$	$\frac{5}{16}$	$1\frac{1}{8}$	$\frac{1}{2}$
$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{23}{32}$	$\frac{21}{32}$	$1\frac{1}{4}$	$\frac{3}{8}$	$1\frac{1}{4}$	$\frac{9}{16}$
$\frac{7}{8}$	$1\frac{7}{16}$	$\frac{13}{16}$	$\frac{3}{4}$	$1\frac{3}{8}$	$\frac{7}{16}$	$1\frac{7}{16}$	$\frac{3}{4}$
1	$1\frac{5}{8}$	$\frac{15}{16}$	$\frac{27}{32}$	$1\frac{5}{8}$	$\frac{1}{2}$	$1\frac{5}{8}$	$\frac{3}{4}$

Formerly all joints of boilers were riveted by hand, but now all riveting is done by machines, except those joints to which a machine cannot be applied. If done by hand, the red-hot rivet is inserted in the hole, and the second head formed by two riveters working with hammers. This head is either made conical by the hammers alone or finished with a cup-shaped die called a "snap." This latter is the more usual method. The disadvantages of hand riveting are slowness and a tendency to form a shoulder before the rivet fills the hole.

Machine riveting is preferable, as the work is done better, faster and more accurately; the pressure coming gradually on the entire rivet, compresses it completely into the hole before the head is formed. Before riveting, care should be taken that the plates are close together, so that a shoulder will not be formed between the plates and prevent a good joint. Rivets should always be put in while red hot, for in this condition they are more easily worked, and when they cool they contract, nipping the plates together in a tight joint.

Hydraulic riveting is more gradual and is generally preferred to steam riveting. The pressure from the steam riveter often comes as a sudden blow and does not allow time for the rivet to completely fill the hole.

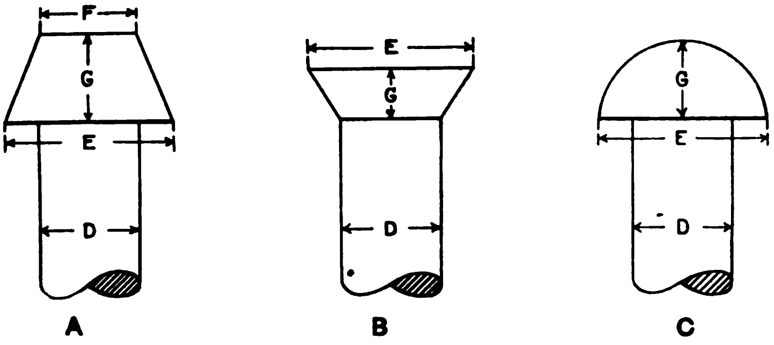


Fig. 4.

It is sometimes desirable to rivet with a countersunk head; that is, the rivet does not project above the plate. The countersunk head is formed by hammering down the end of the rivet into the countersink in the plate. This form is shown at D, Fig. 3. This joint is often used in shipbuilding and in boiler making when it is necessary to attach mountings. It should always be avoided, if possible, on account of its weakness, and especially when the straining force acts in the direction of the length of the rivet, as the head has a very insecure hold and is likely to be pulled through the hole.

Rivets may be tested in a boiler shop as follows: the rivet to be bent cold in the form of a hook around another rivet of the same diameter, and show no flaws or cracks; to be bent hot down upon itself and show no cracks, head to be flattened while hot until its diameter is 2½ times the diameter of the shank, and show no flaws.

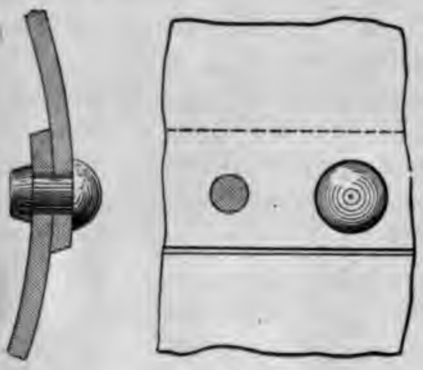


Fig. 5.

The uniform heating of steel rivets is of more importance than in the case of iron rivets, where it is sufficient to heat the points only. Steel rivets also should not be heated to a white heat, as iron rivets are, but to a bright cherry red, for if heated beyond this point they will burn. The fire in which steel rivets are heated should be kept thick, and the draught moderate. This should also be observed in heating steel plates for flanging.

There are various forms and strengths of riveted joints. It is obvious that in punching or drilling, a plate is weakened to the extent of the sectional area cut out, and that if the holes are punched, the metal between the holes is weakened. In treating the strength of a joint it is customary to speak of it as a percentage of the strength of an unpunched plate.

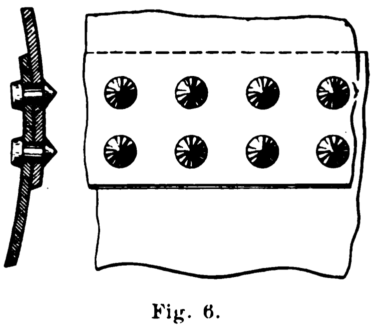


Fig. 6.

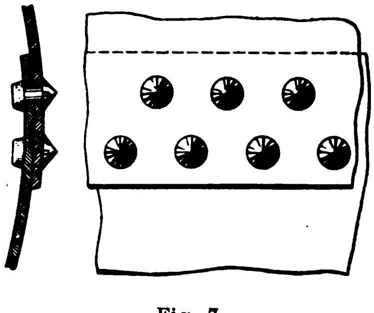


Fig. 7.

If one plate overlaps another and is riveted to it by a single row of rivets, as shown in Fig. 5, it is called a single-riveted lap joint. This joint has about 56 per cent of the strength of a solid plate. If another row of rivets is added, it is called a double-riveted lap joint; Fig. 6 shows the double-riveted lap joint chain riveted, and Fig. 7 the double-riveted lap joint zigzag riveted.

Double riveting is done in two ways: zigzag, or staggered, and chain. When rivets are put in so that the rivets of one row are opposite the spaces of another row, it is called zigzag riveting or staggered riveting. If the rivets are placed immediately opposite each other, it is called chain riveting.

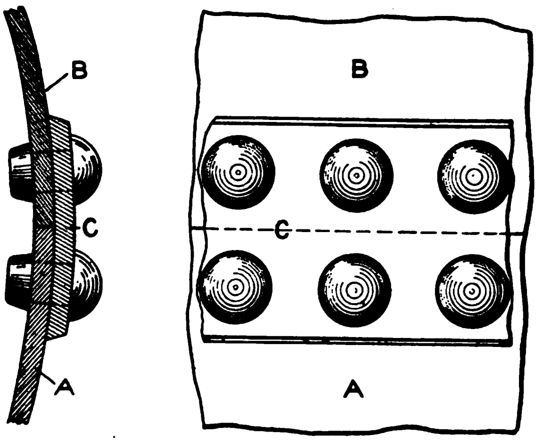


Fig. 8.

If the two plates are kept in the same plane and a cover or butt strap riveted on, it is called butt riveting (Fig. 8, in which A and B are the boiler plates, and C is the butt strap). If an inside butt strap is added, it is called a double butt joint (Fig. 9). Fig. 10 shows a treble-riveted butt joint. A single butt joint is about equal in strength to a lap joint having but one row of rivets, but a double butt joint is considerably stronger.

In this latter form of joint the rivets have double shearing surfaces, since they tend to shear off in two planes. This either makes a stronger joint or allows the use of smaller rivets. In the single butt joint the butt strap is usually about $1\frac{1}{8}$ the thickness of the plate, and if the inside butt strap is added, each butt strap is made about $\frac{5}{8}$ the plate thickness. Butt joints are now being used in the best class of boilers, and are used almost entirely for plates less than $\frac{1}{2}$ inch in thickness.

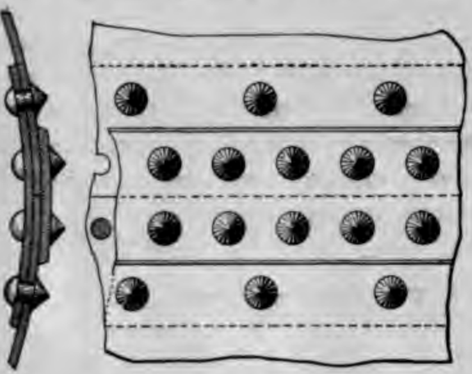


Fig. 9.

Lap joints are used for circumferential seams, and the stronger joint, the butt, for longitudinal joints. For high pressures in marine boilers, triple riveting is frequently used.

If a cover plate is riveted on the outside of a lap joint, it is called combined lap and butt joint. In this case there are three rows of rivets, the middle row having twice as many rivets as the outer rows. Fig. 11 shows the combined joint.

The distance between the centers of rivets is called the "pitch." The mathematical calculation of pitch and the distance between the rivets and the edge of the plate will be taken up later.

The following table gives an idea of the relative strengths of riveted joints:

Kind of Joint.	Riveting.	Percentage of Strength.	
		Punch.	Drilled.
Lap	Single Double	55 69	62 75
Single Butt	Single Double	55 69	62 75
Double Butt	Single Double	57 72	67 79

FLANGING IRON AND STEEL PLATES.

Iron plates are more severely tested by flanging than by any other work done upon them. This is due to their fibrous nature, and great care is necessary to prevent breaking in the bend, if the corner is sharp.

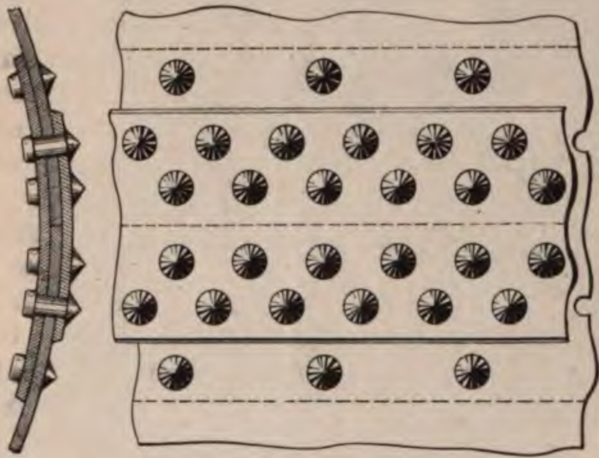


Fig. 10.

As has been stated, steel requires uniform heating and moderate curves. Flanging is almost entirely done to-day by machines. After flanging, the steel should be annealed by heating the whole plate uniformly to a dull red heat, and allowing it to cool slowly.

WELDED JOINTS.

Welded joints for boiler shells are desirable. By their use deposits which accumulate on and around rivet heads and joints, corrosion caused by leakage, and loose rivets, are done away with, and calking also. Moreover, a perfectly welded joint is stronger than the best riveted joint, and approximates nearly to the original strength of the plate. Welded steam drums are used now quite extensively for water-tube boilers of the marine type.

The soundness of such a joint is a matter of uncertainty, and depends upon the skill and care of the workmen. It is impossible, from external appearances, to judge the soundness of a welded joint. The principal use of welded joints is for furnace tubes and steam domes, but they have not been used much for boiler shells. The lack of tests on welded joints and the small amount of information on the subject, render the results of experiments of little value. The weld is best made when the edges of the plates are upset, at red heat, to nearly double the plate thickness, and beveled to an angle of about 45 degrees. The edges are then heated together, and the weld made by hammering down the joint to the original thickness of th plate.

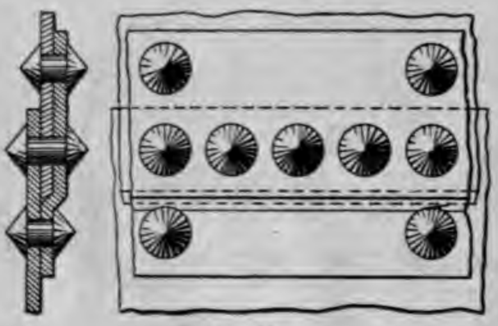


Fig. 11.

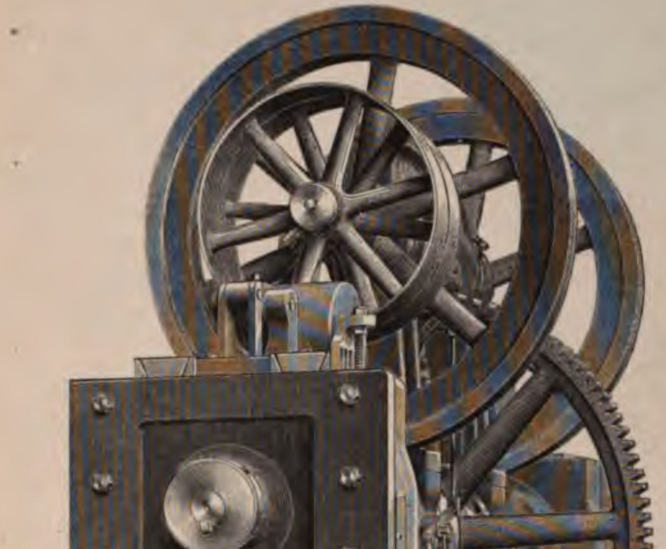
ARRANGEMENTS OF PLATES AND JOINTS.

When we take up the design of boilers we shall see that a boiler tends to rupture longitudinally. The reason for this is that the resistance of a thin cylinder to circumferential rupture is double the resistance to longitudinal. Since this is the case, lap joints are used for transverse seams, and a stronger form (the double butt joint) is used for the longitudinal.

At the junction of three or more plates, where the circumferential and longitudinal joints meet, ordinary riveted joints would be too thick. To overcome this difficulty, two or more plates are forged thin at the joint, as shown in Fig. 12.

Whenever longitudinal and girth seams meet, the plates should be arranged to "break joints"; that is, one longitudinal seam should not be a continuation of another. The proper arrangement is shown in Fig. 13.

In both vertical and horizontal boilers the inside lap is made to face downward, so that it will not form a ledge for the collection of sediment


THE LONG & ALLSTATTER CO.
HAMILTON, OHIO. U. S. A.
439

HEAVY DOUBLE GANG PUNCH.
The Long and Allstatter Co.

t should be the diameter of a piece as it comes from f it is to be ground to a diameter of 4 inches?

16. According to Addy, how long would it take to mill a cast iron surface 18 inches long, and 16 inches wide, with a milling cutter 6 inches in diameter and 3 inches wide.

17. How is a surface prepared for laying out work?

18. How are temporary joints made?

19. How many horse-power may be safely transmitted by a gle belt 8 inches wide, running over a 36-inch pulley which kes 175 revolutions per minute?

20. State some of the uses of the milling machine.

21. How are case-hardened pieces usually finished?

22. What tools are used for laying out work? Explain the ction of each.

23. Why should a lathe or planer tool work beneath the face of a casting?

24. How may the power transmitted by the belt in Question be increased to 32 horse-power?

25. According to Addy's rule, what should be the speed of a milling cutter 8 inches in diameter when working in cast iron?

26. Which is preferable for high polish, new or old emery cloth? Why?

27. If the feed is 1.5 inches per minute, how long will it take to cut a groove 2 inches wide, 4 feet long, $\frac{1}{4}$ inch deep? The material is soft machinery steel, and the milling cutter is $2\frac{1}{4}$ inches in diameter and $1\frac{1}{4}$ inches wide.

28. Should work be calipered while at rest or while in motion?

REVIEW QUESTIONS

ON THE SUBJECT OF

CONSTRUCTION OF BOILERS.

1. If they are near together how are two flat parallel surfaces stayed?
2. Describe a rivet.
3. Since copper is such a desirable metal for boiler work why is it not used more extensively?
4. Why is a large factor of safety used for stays?
5. State what you can (briefly) about the injuries done to plates by punching and the methods employed to overcome them.
6. Why are not welded joints used more generally?
7. In what two ways are tubes fastened to the tube sheet?
8. About what is the ratio of length to diameter of the multitubular type of boiler?
9. Explain riveting with countersunk head.
10. Is the greatest tendency to rupture along the longitudinal or the circumferential seams?
11. Why is the length of a grate limited?
12. Which is the stronger form of riveting, the lap joint or double butt joint (both with double riveting)?
13. Why are the short screw stay bolts turned smooth in the center?
14. Why are flanged joints preferable to those made with cast iron angle irons?
15. What is the water-leg?
16. For what qualities are boiler materials tested?
17. What is the principal advantage of pneumatic calking?

on of a boiler between the shell and the furnace is ter leg. Figs. 14 to 20 inclusive illustrate the nstruction of the water leg and the joints around the e door. Figs. 14 and 15 show two methods of constructing the water leg. In Fig. 14 the exterior plate and the furnace plate are riveted to the ring D by means of long rivets. This ring is usually made of wrought iron, but in many cheap boilers it is of cast iron. In Fig. 15 the two plates are riveted to the flanged ring D. This construction is better than the solid cast-iron ring, on account of flexibility, but the junction of the plates D and C

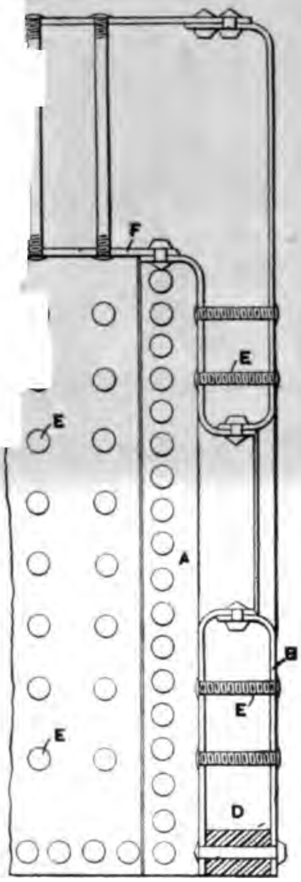


Fig. 14.

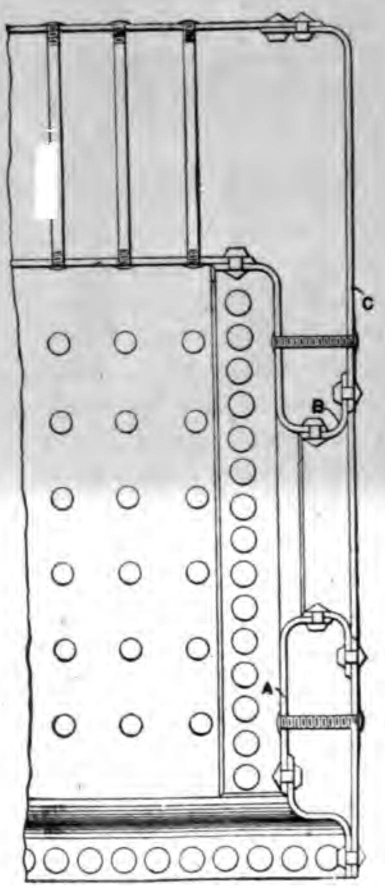


Fig. 15.

forms a corner in which sediment is deposited. In Fig. 17 the plate B is flanged and riveted to C. This arrangement requires less riveting than the one shown in Fig. 15. Figs. 14, 15 and 17 also show three forms of construction of the joints around the furnace door. In Fig. 14 both the exterior plate and the furnace sheet are flanged and riveted together. This is shown in an enlarged view in Fig. 18. The construction shown in Figs. 15 and 19 is not as good as that in Fig. 14, because of the extra riveting; also, it has two corners, B and C, for the deposit of sediment. Fig. 17 shows a somewhat different form of furnace construction,

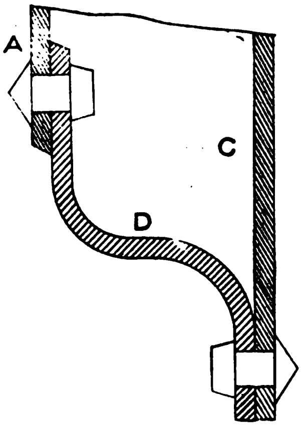


Fig. 16.

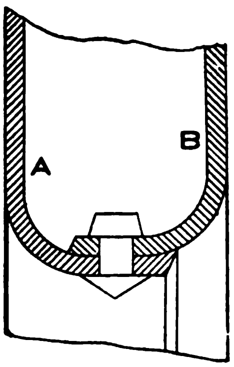


Fig. 18.

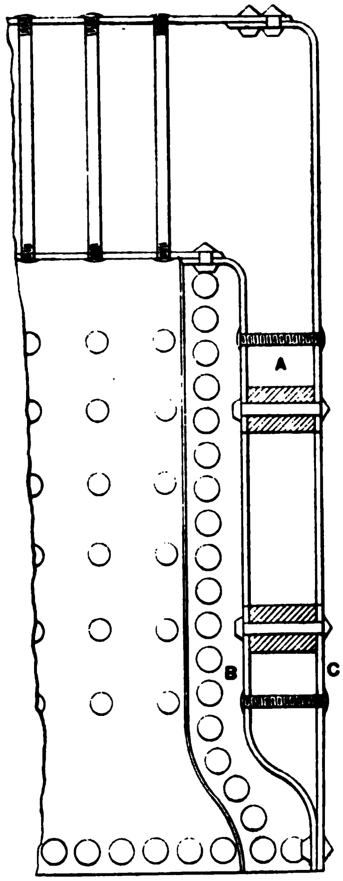


Fig. 17.

shell are sometimes connected to a flanged ring, as shown in Fig. 24. The extra row of rivets makes a complex joint.

In vertical boilers the external fire-box is joined to the cylindrical shell by riveted joints. Figs. 25 and 26 show two forms; that in Fig. 25 being the better on account of the flanged ring, which allows expansion and contraction of the shell and furnace plates.

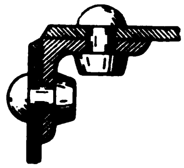


Fig. 21.

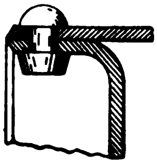


Fig. 22.

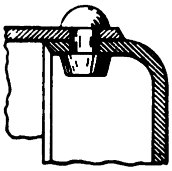


Fig. 23.

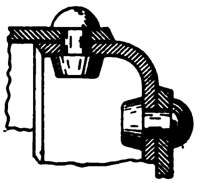


Fig. 24.

Sometimes the case occurs of connecting two plates which are parallel and near together. For instance, at the bottom of the locomotive fire-box a connection must be made between the inner and outer fire-box. The water-leg construction is a similar case. Several methods for this construction are shown in Fig. 27. Fig. 27A is too complicated and is undesirable, both on account of the numerous rivets and angle irons, and on account of the inside joints, which cannot be calked. Fig. 27B is better, since it has but one angle iron; it has, however, the undesirable inside joint.

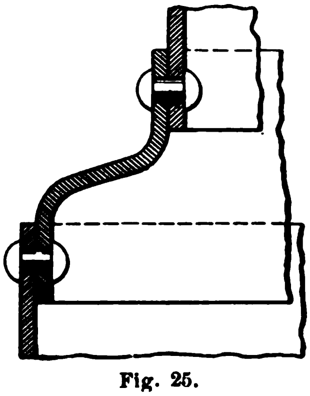


Fig. 25.

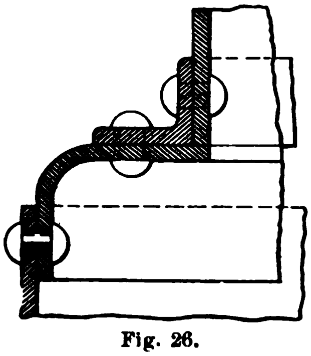


Fig. 26.

Fig. 27D is a good joint, the form of connection being called a channel iron. Fig. 27E, as we have seen, is a good flexible joint, but it has the undesirable corner where sediment lodges.

We have thus briefly discussed the various methods and arrangements for putting shells together, and now let us return to our boiler, which is ready for riveting at the hydraulic riveter. A few rivets are first driven at equal intervals around the ring seam at the back head. The reason for driving only a few rivets is that any errors in the spacing of the holes are distributed and not accumulated, as would be the case if they were driven in succession. From this point on, the riveting is continued until the shell is completely riveted up.

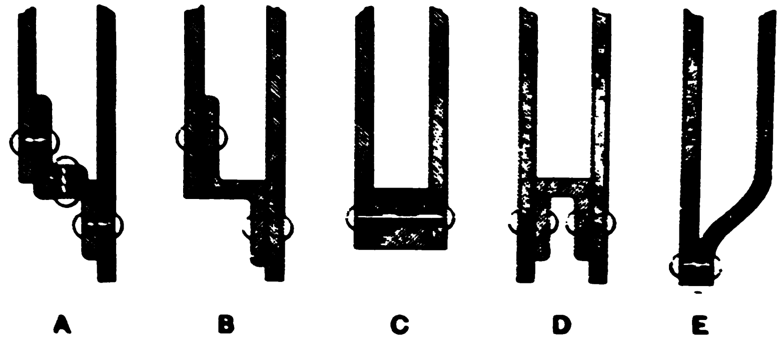
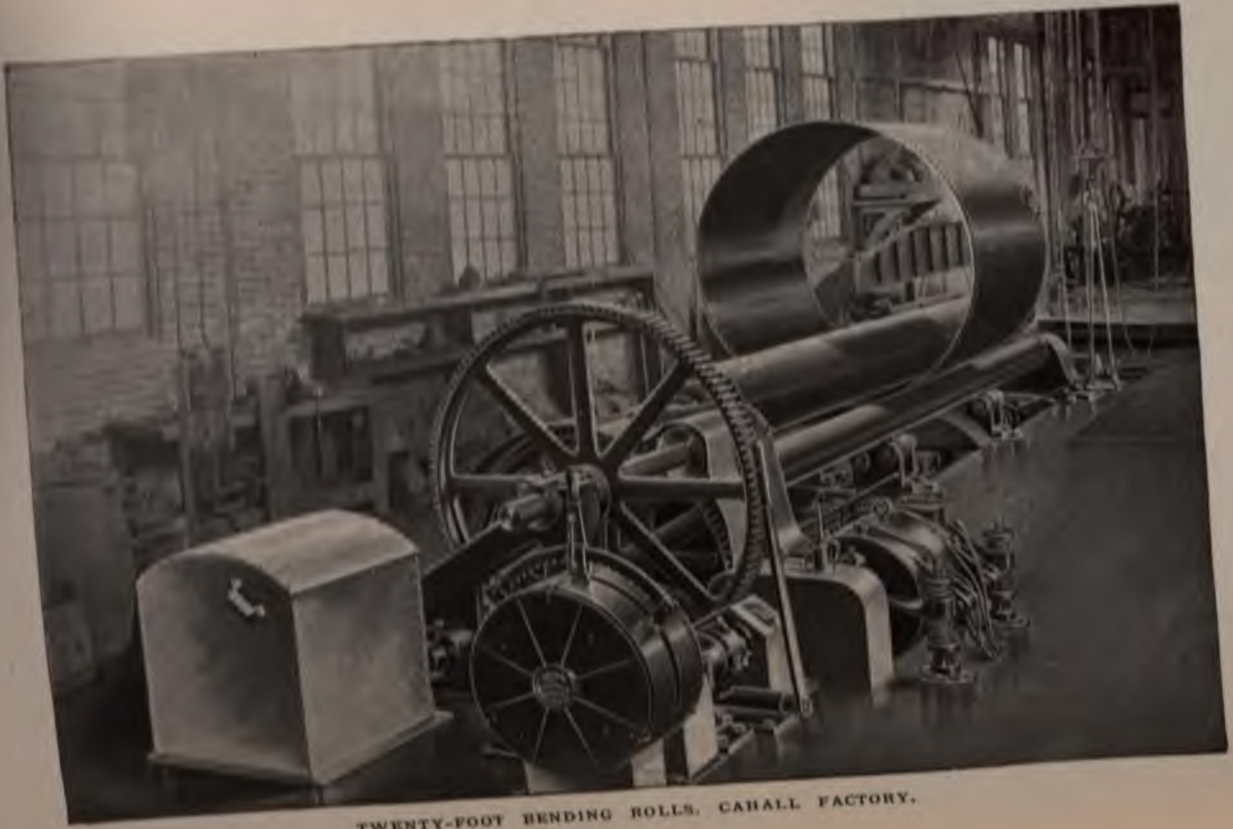


Fig. 27.

STAYING.

The shell is now ready to receive the stays. When under steam, a cylindrical shell is strained by internal pressure in two directions, namely: transversely, by a circumferential strain due to the pressure tending to burst the shell by enlarging its circumference, and longitudinally, by the pressure on the ends. If a boiler were spherical it would require no stays, because a sphere subjected to internal pressure tends to enlarge but not to change its shape. All flat surfaces in boilers must be stayed, otherwise the internal pressure would bulge them out and tend to make them spherical in shape. The ends of steam drums on high-pressure water-tube b[illegible] hemispherical.

T[illegible] point in staying is to have a



TWENTY-FOOT BENDING ROLLS. CAHALL FACTORY.